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PUMPS AND PUMPING

A Hand-Book for Pump Users

BEING NOTES ON
SELECTION, CONSTRUCTION, AND MANAGEMENT

BY

anfred C.C.
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'GAS AND OIL ENGINE MANAGEMENT,' ETC.

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PREFACE.

The large measure of success attained by the author's "Hand-book for Steam Users" has induced him to write the following pages on similar lines. The literature likely to be of service to pump users hitherto published has been extremely scanty, and it is hoped, therefore, that the notes to be found herein may prove acceptable and useful. Within the scope of the work it has been impossible to notice all the varied pump combinations, and some of the remarks made must be considered general and not exhaustive.

Some notes on design will be found interspersed with the text, but the author wishes it to be understood that the book is not intended as a treatise on the construction of pumps.

The matter has been condensed as much as possible, and is arranged in the form of headed paragraphs for easy reference.

APPOLD STREET,
LONDON, E.C.
June, 1889.

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PUMPS AND PUMPING.

CHAPTER I.

STEAM PUMPS.

Classification of Pumps.—As we shall constantly have to refer to the different types of pumps it may be as well, to avoid confusion, to broadly classify them and briefly explain their action. They may be roughly divided into five classes—viz., (1) Lift Pumps; (2) Plunger or Force Pumps; (3) Centrifugal and Rotary Pumps; (4) Mechanical Water Lifters; (5) Injectors. These, again, may be subdivided into a multiplicity of types and combinations adapted for the varied duties they have to perform.

(1) *Lift Pumps.*—Are those in which the water is drawn through a suction pipe as the pump bucket ascends, is forced through the bucket valve as the pump descends, and is lifted again by the bucket as it re-ascends.

(2) *Plunger or Force Pumps.*—Are those in which the water is drawn through a suction-pipe and is displaced by the action of a plunger or piston which forces it through a delivery valve. A combination of Classes 1 and 2 is made

in which the lift pump bucket is combined with the plunger or piston of a force pump. Single and double acting force pumps are also used extensively; in the former the water enters the Pump during one stroke of the plunger or piston and is forced out at the next stroke, the delivery of water is therefore intermittent. In double acting force pumps, the discharge though fluctuating somewhat is practically continuous, the water being drawn in at one end of the plunger whilst it is being forced out at the other. Various other combinations of these two chief classes of pumps are constructed and modified in details, and arranged to work either vertically or horizontally as the nature of the duty or convenience may dictate.

(3) *Centrifugal and Rotary Pumps.*—Centrifugal pumps consist briefly of a fan or disc fitted with impellers revolving inside a casing or chamber which create a partial vacuum in the chamber sufficiently powerful to draw the water through it. Rotary pumps may be classed as revolving piston pumps in contra-distinction to direct acting pumps.

(4) *Mechanical Water Lifters.* — These include the different plans for raising water by means of buckets arranged on revolving chains and wheels, chain pumps, scoop wheels, &c.

(5) *Injectors.*—These include the different instruments by which water is raised or forced through the momentum obtained from a jet of steam acting directly on the water itself, which at the same time condenses it.

Selection of a Pump.—It need hardly be said that the selection of a pump, exactly adapted in type, size, and ement for the duty it has to perform, is a matter of vital importance to its successful and economical working. Sufficient attention is not, however, always given to these points, or a user is sometimes persuaded by a pump maker that his own particular pump is adapted for almost any kind of duty, and a purchaser finds himself saddled with a machine unsuited to his requirements and a continual source of trouble and annoyance. In selecting a pump each case should be judged strictly on its merits, and as these must of necessity vary very largely, it is impossible to formulate any arbitrary instructions on the subject; but in these pages we purpose pointing out briefly some of the duties each type of pump is suited for, and some of the points to be desired in its construction. As we have elsewhere remarked, pumps are now arranged in a great variety of ways, to suit varying circumstances. and the author trusts these notes may aid non-technical users in making a suitable choice.

In selecting a steam pump, for whatever purpose it may be required, the chief points to be desired are—(1) Simplicity, strength, good workmanship, with easy access to the working parts for adjustments or repairs; (2) Certainty of action; (3) To work well at varying speeds and with moderate expenditure of power; (4) To deliver a fairly constant stream of water. Simplicity of construction in a pump is a matter of very great importance, as it is often placed in a position or country where repairs are difficult and expensive, and should a breakdown occur great damage and loss may arise. The working parts of a pump should therefore always be so designed that they can be readily replaced in case of wear. It will be found economical in choosing a pump to secure one well above its work, as it can be run at a slower speed for the duty required, consequently its wear and tear reduced. Steam pumps of somewhat complex construction are in use which give high results theoretically, but in practice these are rapidly counterbalanced by the extra cost of renewals, breakdowns, &c. Speaking generally, a long stroke pump, where it can be used, is to be preferred to a short stroke one, especially in the larger sizes, as making fewer strokes per minute for the same piston speed the inertia to be overcome is lessened. The increased friction of the water in the pump passages, &c.—owing to the constant reversals and alterations of its flow in short stroke pumps—is also reduced, and the wear of the working parts lessened, at the same time the pump has a better chance of completely filling itself at each stroke.

It need hardly be said the suitability of the valves, both water and steam, for the duty to be performed is a matter of critical importance to the efficient working of a pump, and some notes thereon will be found elsewhere, also remarks on the different types of pumps for different duties. In selecting a steam pump it must be borne in mind that the power of a pump does not altogether depend on the diameter and stroke of the steam and pump cylinders; the mean pressure of the steam used, the speed of running, the arrangement and area of the valves and passages, &c., are also important factors in this connection. It should also be remembered that a slow piston speed gives a good vacuum and therefore a better useful effect. In calculating the size of pump necessary, the chief factors are—(1) depth of suction and load on pump: (2) the loss through leakage or "slip"; (3) the height and distance water has to be forced; (4) the friction of water through pump pipes and bends; (5) the inertia to be overcome, and, in the case of steam pumps, (6) the steam pressure available. Whether the pump selected should be of the piston or plunger variety must of course depend largely on the duty it has to perform, as both types possess advantages and disadvantages. When the packing and cylinder is in a first-class condition a bucket or piston pump will produce a better vacuum, and therefore a fuller pump than a plunger will do. It works, however, with more friction, and a considerable leakage of water from worn packing may be going on and remain for some time undetected. The cost and loss of time in renewing the packing must also be taken into account. Plunger pumps can be packed either internally or externally at a moderate cost, and in the latter case leakage can be detected. Speaking generally, in cases where it is necessary that a first-rate vacuum must be maintained, such as in lifting a considerable distance by suction, lifting hot liquids, &c., the features of a piston pump commend themselves, whilst for rough duties and heavy pressures the plunger pump is to be preferred. A purchaser would do well in all cases to bind the manufacturer as to the number of gallons his pump will discharge under certain stated conditions, or he will find there is often a vast disparity between the theoretical and actual efficiency of a pump, or, in other words, the amount of water discharged is much less than it is theoretically calculated to be.

Direct Acting Steam Pumps.—Direct acting pumps—or those which have no rotary motion—of various forms are more largely used than any other steam pumps. There exists, in fact, such a multiplicity of classes or combinations designed to suit varying duties that it will be impossible to do more in these pages than to notice briefly some of the most important ones. In a large number of direct acting or reciprocating pumps both steam and water cylinders are mounted on a cast-iron bed plate, and as the same piston-rod has to work the steam and water pistons it is a plan that can be generally commended, as rigidity and perfect alignment can be readily secured. Many attempts have been made to combine as much of a pump as possible in one casting. Although this arrangement may, in the first instance, have something to commend it on the score of cost, in case of fracture the renewals are made very expensive. A number of pumps are also made with the steam and water cylinders mounted on feet and joined together by a tubular casting ; this plan lessens somewhat the cost of production. In the smaller pumps of the best class the pump cylinder, &c., is usually made of or bushed with gun metal, and this will be found absolutely necessary with some liquids which attack iron, upon which notes will be found elsewhere. Steam cylinders should be made of hard, grey cast-iron, lagged and fitted with lubricator and drain locks, and as accurately bored and fitted as a first-class steam engine, with piston rods and pins of steel joints case-hardened, &c.

It need hardly be said the most important factors in the successful working of a pump are the steam and water valves. Referring first to the steam valves, a great variety of these are constructed, some moved by steam, hydraulic pistons, tappets, levers, and other gear. Most of these have some features to commend them; but for certainty of action, freedom from disarrangement, and simplicity of construction, the author prefers wherever it can be conveniently employed, the ordina *flat slide* valve working over ports, as in a stea engine, to any other form he has used. It may be urged that some extra power is absorbed in working this valve, especially if driven by an eccentric; but even admitting this for the sake of argument, although it is not by any means certain, at any rate when compared with steam moved valves, it is more than counterbalanced by the many advantages of this form of valve. A sufficient proof of its excellency may be deduced from the fact that in the case of steam engines it has more than held its own for many years. Should the pump be subject to rough usage or be allowed to stand idle for some time, unlike other valves with more delicate mechanism, no difficulty is found in re-starting this one.

Owing to their not working expansively, direct acting steam pumps have the disadvantage of using a considerable amount of steam; this is especially the case with some forms of steam valves. Condensers can, however, be fitted to them, and effect an appreciable saving, and as they also get rid of the exhaust steam should be particularly useful in underground work, tunnelling, &c. A simple form of condenser in some cases can be made to form part of the suction pipe, and the vacuum it maintains of course adds to the power of the pump. Again, direct acting pumps are not always certain in their action; this may arise in many cases, as we elsewhere remarked, from delicate or complicated mechanism of the steam valve motion. With the object of making them absolutely positive in the action, in some pumps of recent construction, instead of depending on the action of steam or tappet to operate the steam valves, they are connected mechanically with the main piston, thus rendering their action certain. For regulating the piston speed to the nature of the duty of the pump a small supplementary hydraulic cylinder and piston acting on the movement of the main steam valve has been introduced with success, the speed of the pump being increased or decreased as the flow of the water from one end of the hydraulic cylinder to the other is permitted or retarded.

A pump arranged with a steam cylinder and flat slide valve worked by an eccentric from a crank shaft can be worked expansively, an economical advantage not possessed by direct acting pumps. Instead of an ordinary eccentric rod for working this form of valve some makers employ a vibrating arm or lever, and it is claimed for this arrangement that it can be worked with less friction than the eccentric, and is therefore more durable, is more certain in action than a steam moved valve, and is worked with less friction than when the valve is thrown open with a blow on a tappet. Steam and tappet moved valves have both their advocates, but with the latter form we have had more than one case where we have been compelled to use dirty steam where the tappets have become jammed (see also "Pump Valves"). Direct acting pumps possess the advantages of being capable of being used for a great number of purposes—they occupy little space, are readily erected, and are low in first cost and maintenance; they are not, however, always certain in their action.

Fly-Wheel Pumps.—Fly-wheel pumps possess some advantages over direct acting pumps, notably in the saving of steam, which is very considerable when they are worked expansively, and when the valves of direct acting pumps are blown across the ports by jets of steam. The stroke is also positive, and there is no waste of steam through irregular strokes, as is sometimes the case with direct acting pumps. Ordinary flat steam valves can be recommended for this form of pump, with the clearance and cushioning of the piston as with a steam engine. Unlike direct acting pumps it is not necessary in the case of fly-wheel pumps that the full pressure of steam should be used throughout the stroke; but the cut off or rate of expansion can be varied to a certain extent to suit the water pressure it has to work against. Again, the stroke being positive and limited by the crank, much less clearance in the cylinder is required, it being impossible for the piston to over-run its stroke. Vertical fly-wheel pumps are used considerably, and being more compact than horizontal are well suited for limited spaces, at the same time their cylinder wear is less. Owing to the limitation of the stroke by the crank and the regulating and compensating action of the fly-wheel, pumps of this type can be run at their full speed with safety.

Many fly-wheel pumps combine steadiness in running and certainty of action with considerable economy of steam. They are made of both horizontal and vertical types, with single or double acting ram, or other pump, as the duty may require. In the horizontal type the fly-wheel and shaft are usually placed in the centre of the pump, between the steam and water cylinders, the piston rods being worked by connecting rods, the "Kite" pattern being largely used for this purpose. If, however, the pump is required to drive by belt the steam cylinder is done away with, and the fly-wheel, with fast and loose pulleys, is fitted in its place at one end of the pump. An improved form of piston valve for the water cylinder *is now made for* which it is claimed that "slip" or leakage is largely done away with, the valve being balanced, moved automatically, and opened and closed uniformly with the speed of the piston, the ports being open at their widest during the maximum flow of the water. We may add we have tested several of these pumps with satisfactory results, and they possess the unusual feature in a pump of being capable of being reversed, which may be found of service in cleansing the suction pipe when choked.

A double acting ram or plunger pump has recently been introduced in which the ram for both pumps is made in one piece, and these are driven from one steam piston after the manner of a direct acting steam pump. By this arrangement one valve box is made to do duty for both pumps, thus reducing the pump's parts. The pump is driven by a steam cylinder, with crank and fly-wheel as in a steam engine, and the steam valve is an ordinary flat slide valve operated by an eccentric rendering its action absolutely positive. For heavy pressure and rough usage these pumps can be recommended; they should be of simple construction, compact, and strong, and have fly-wheels of ample dimensions and weight to ensure certainty and ease of action. The rams or plungers should be cased, and glands bushed with gun-metal, and gun-metal pump liners will be found very useful and are readily renewed. The valves and seats are for most duties best made of gun metal, especially for long suctions.

Ram or plunger pumps will work with less friction than a packed piston and are somewhat easier to keep in order, and they are particularly well-suited for heavy pressures and also for gritty water, where a centrifugal is not available. It is found in practice that a well constructed fly-wheel pump with ordinary flat valves will use less steam and work with less shock at the end of the stroke than pumps whose valves are steam moved, or blown to and fro by jets of steam; but whatever form of valve is used to secure easy working of the pump with freedom from jar, it is necessary that the piston should receive a cushion of steam at the instant of reversal, and there is little doubt that unsatisfactory working often attributed to other causes has often arisen from the neglect of or improper way of carrying this out. As we have elsewhere remarked, a considerable loss of effect may arise also from badly designed water chambers and the consequent difficulty of getting rid of the lurking air. The cross-head and other bearing and working parts of these, and, in fact, all pumps, should be made as far as possible adjustable for wear, as it will save a considerable amount of lost time occupied in adjustments and repairs. It will be found also a good plan to keep duplicate sets of wearing parts in stock, and as these are generally made to template no difficulty should arise in fitting. In working plunger or force pumps, it is important that when the plunger is reduced in diameter from wear that it be renewed, as the air between the plunger and pump-barrel may be sufficient to expand and compress without lifting the valves, thus causing the pump to fail. If it is required to run fly-wheel pumps very slowly, this may be done when necessary by gearing them down from the fly-wheel shaft. Plunger or force pumps are sometimes made with a hollow ram fitted with a delivery valve; the water in this arrangement as it rises passes directly through the ram, and the direction of its flow is not reversed as is the case with a solid plunger.

Some Points to be desired in a Steam Pump.—The following may be said briefly to be some points to be desired in a steam pump—(1) Strength and simplicity of working parts; (2) Long stroke and ample wearing surfaces; (3) Certainty of action in steam and water valves; (4) Large water valve area with low lifts and ample water ways; (5) To throw a continuous stream of water; (6) To be capable of running with steadiness at various speeds and pressures of steam; (7) To start at any point of the stroke; (8) Working parts capable of being quickly examined and adjusted; (9) Good design and workmanship; (10) A moderate consumption of steam; (11) To run without pounding under light or heavy duty.

Cornish Pumping Engines.—For draining mines and forcing large quantities of water to a great height the single-acting Cornish pumping engine has been for many years and is still chiefly employed. It is not surpassed by any other system in durability and economy of working, although it presents the drawbacks of large first cost, expensive foundations, engine house, &c. In very deep mines each level is usually provided with a separate tank, into which successively the water is pumped and raised; this plan, although successful, of course adds much to the working parts, &c., as a pump is fixed at each level and worked from the main pump rod. The first or lowest pump is an adjustable bucket-pump, which can be raised or lowered as desired; the second pump s a plunger and takes its water from the first tank, it is more powerful than the first pump, and in succession each pump is increased in size to the top of the mine. Although the first cost is considerably increased by this arrangement, it possesses the advantage of being capable of draining several levels at the same time.

Pumps arranged with balancing columns of water have also been tried for mine drainage, but have not come into general use. Engines for this duty are also made compound and condensing. The pumps should be of simple construction and free from delicate mechanism to avoid liability to disarrangement. Where mine water is corrosive, wood, leather, or soft metal is used for the pump valve seating instead of metal. The pipes have usually flanged joints and are generally lined with wood to prevent corrosion. The pump rods are generally of wood bound with metal plates. The pumps employed are either lifting or forcing pumps, or a combination of the two. The pump valves are usually the double or treble beat, the ordinary clack or conical valves being unsuitable, as owing to the heavy pressure of the water, they are found to close themselves with too great violence and therefore rapidly deteriorate. The double beat valve, on the other hand, will allow a considerable body of water to pass with a very moderate lift, and will close without a great amount of friction to the valves and seats.

Pumps for Underground Work, Tunnelling, &c.—Various forms of direct acting pumps are now employed for mine drainage in lieu of the beam engine and pumps, and although they are not so economical in working as this latter, they being fixed underground, possess the advantages of dispensing with an engine house and expensive foundations as well as being lower in first cost. The duty of mine pumps is very severe and constant. Double plunger pumps, with external glands, are generally preferred for this work, where there is a heavy pressure combined with sandy water, &c., as there is less leakage and wear than with piston pumps having a similar duty. Where extreme economy of working is desired the pumps are compounded and fitted with a condenser. The pump barrels should be lined with gun metal, and the valves, &c., be made of the same material. In one make of pump the water valves consist of a number of small valves with a low lift arranged in a series of chambers, and in another a large number of ball valves are used. For tunnelling, &c., purposes compressed air will be found a very convenient power for working pumps.

Hydraulic Pumping Engines.—These are used chiefly in large mines as an auxiliary aid to the ordinary pumps in case of stoppage or flooding. They work on the principle that the power from a smaller head of water from a greater height will raise a greater quantity of water to a lesser height, or, in other words, a small quantity of water at a great pressure will pump a larger quantity at a less pressure. Where the pressure is considerable or the water dirty, double acting ram pumps are usually employed. The action of an ordinary form of hydraulic engine is as follows: When the sluice valve is opened on the inlet pipe, the water enters through the port into the cylinder, and pressing upon the piston pushes it to the other end. Just before it arrives at that point, a lever of a four-way cock is caught by a tappet, which is moved by the piston rod, the motion is reversed and the piston rod brought back again, and so on alternately. In some pumps pistons have been dispensed with, the power being applied to and the work done by power plungers so arranged that the forcing stroke of one pump plunger causes the suction stroke of the other.

High-pressure Pumps for Waterworks, &c.—For

heavy pressures, such as forcing through mains, &c., pumps driven by Cornish single acting engines, low pressure condensing beam, direct acting compound and condensing, and, in the most recent practice, by engines arranged with quadruple expansion are employed, according to the cost of fuel and other circumstances. The different types of beam engines have much to commend them for this duty, as they combine great steadiness in working with extreme economy in the consumption of fuel. Double-acting plunger and single-acting bucket pumps are the type perhaps most largely employed. They are made with considerable length of stroke to lessen the number of reversals, loss from clearance, and wear on the valves. In addition to this, with the object of allowing the pump valves to close without shock, some makers—by cushioning the steam cylinder—arrange that the piston shall pause at the end of each stroke, thus enabling the valves to close quietly. Double, treble, or quadruple beat valves made of gun metal are usually employed, special means being taken to reduce the pressure on the seats of the valve as far as possible. Groups of gutta-percha ball valves working on metal seatings have also been used with success. In large high pressure pumps it is especially important that the flow of water is as continuous as possible, and the shocks and friction due to the change of direction of a heavy body be minimised as far as may be. Passages and valves should be free and be designed so as to give as little accommodation for the accumulation of air as possible. Relief valves are fitted to the delivery mains, and a supplementary cut-off apparatus should be fitted to stop the engine racing should a main pipe burst or the governor gear be out of order. Where delivery mains are laid on a rise, back-stop valves have been fitted in several recent cases; this prevents the return of the water should the engine stop or a pipe burst at a lower level. In the case of long mains or very heavy pressures air vessels are of little use, it is important, therefore, to avoid shocks or undue strain, that a pump is used with a slow piston speed, and which will work with slight variation in speed and give a steady and even delivery of water.

Compound Steam Pumps.—Many attempts have been made to work ordinary direct acting steam pumps expansively, but with little or no success. The best we have seen is through the medium of a steam-moved valve so arranged that steam may be cut off at any desired point of the stroke. Compound pumps have of late years been introduced considerably. The steam cylinders are usually placed either tandem fashion or side by side, and generally so arranged that when the steam has been used in the high pressure cylinder and forced the piston in the one direction, it is expanded into the larger cylinder and drives the piston in the opposite direction, thus completing the stroke. Where fuel is expensive this arrangement should be serviceable. To work compound pumps economically a high pressure of steam should be used, say not less than 100 pounds to the square inch. It has been argued that the increase in the number of working parts necessary in a compound over an ordinary pump, and the increase in first cost, with the friction of working and consequent cost for maintenance and repairs, nearly counterbalances any economy in steam. We cannot, however, coincide in this opinion, and think, other things being equal, that a good compound will, under ordinary circumstances, effect a saving of at least ten per cent. in fuel over an ordinary non-expansion pump.

Duplex Direct Acting Steam Pumps.—This arrangement of pumps is of American origin, and consists briefly in placing two steam pumps side by side, and controlling them both through the medium of flat slide valves, as used in a steam engine. This plan has much to commend it, as it simplifies the construction and consequent wear and tear considerably. They have no dead centres, and as each piston is made to pause at the end of its stroke and the plunger of one pump commences its stroke as the other finishes, ample time is allowed for the water valves to properly seat themselves. Any dead point is avoided by mechanically actuating each steam valve from the piston rod of the opposite cylinder, consequently the pumps can start at any point of the stroke, and will deliver a steady flow of water with little jar or pulsation. The valve motion should be made adjustable. In packing duplex pumps it is important that both sides are packed alike, or they will run unsteadily. This form of pump has been found well suited for charging hydraulic accumulators and other severe duties. (See also pp. 24, 25.)

Boilers for Driving Steam Pumps.—Boilers for driving steam pumps should be of a capacity in proportion to the size of the steam cylinder, without reference to the pump cylinder. For long-stroke pumps, or those having heavy duties, increased boiler space should be allowed, and it will always be found economical in working to have a boiler of a power a little in excess of absolute requirements, as forcing a small boiler means waste of fuel, deterioration of boiler, and sometimes accidents. In selecting a boiler for this or any other duty, the chief points to bear in mind are the nature of the feed water and the *quality of the fuel.* If the feed water is bad and throws down a considerable incrustation of lime, &c., either means must be taken to purify it or a simple form of boiler, easily cleaned or repaired, should be selected. If the fuel is bad increased area of fire-box will be necessary, and in some cases a forced draught will be required. If wood is the fuel used a fire-box one-third larger than is necessary for good coal should be fitted. The boiler should be tested to at least double its working pressure, and arranged with all usual fittings, as when used to drive a steam engine. The use of a feed water heater can also be recommended.

Condensing Exhaust Steam from Steam Pump.—When an ordinary condenser is not employed the exhaust steam from a steam pump or from an engine driving a centrifugal pump is sometimes condensed by forming an annular chamber round the delivery or suction pipes, a pump or trap being fitted to remove the water when condensed. By enlarging the chamber a combination of water jet and surface condenser may be made. Sometimes the exhaust steam is discharged directly into the suction pipe; in these cases, however, it is important that it is not allowed to overheat the water or cause back pressure.

Independent Condenser Pumps.—Owing to the increase of speed in many modern engines, in lieu of a pump driven by the engine it has been found desirable in some cases to employ an independently-driven air pump and condenser. By these means an ordinary high-pressure engine may be made to condense without alteration to existing mechanism. Another form of independent condenser for steam pumps, in which the air pump usua employed is done away with, has also been introduced. In this arrangement the force of the exhaust steam combined with the force of the injection water is employed to drive the vapour into the suction chamber of the pump, where it mixes with the water, and is delivered with it by the pump to the open air. It is claimed for this arrangement that the injection water cannot be drawn into the main steam cylinder, and flooding from this cause is avoided, and should, from any cause, the pump stop working, the vacuum is immediately destroyed, and consequently the injection water ceases to flow.

Fixing Steam Pumps.—Steam pumps should in all cases be fixed as near to the boiler from which they receive their supply of steam and to the water to be pumped as possible. To prevent condensation and loss of pressure the steam pipes should be covered with a good non-conducting composition, and if they are long should be fitted with a steam trap. The author has found slag wool, thick hair felt lagged with wool, and fossil wool all answer well for pipe coverings. Small pumps may be fixed on timber foundations, but large ones should have stone or brick foundations laid in cement. The most convenient way of arranging the foundation bolts is to make a light wooden template showing the holes from the bedplate of the pump, and the bolts can then be cemented in their places if desired. In the case of heavy pumps or pumping engines the foundation bolts should pass entirely through the masonry, if of stone the top blocks should be cramped together and the joints filled in with cement or molten lead. If brickwork is used for a foundation it should be laid on concrete, the bricks be hard and well burnt, and Portland cement used.

Any reasonable outlay in foundations can be recommended as increased stability and steadiness in working is secured. The pump should be fixed at a dead level both horizontally and transversely, and if fixed on an upper floor the vibration of working will be deadened by placing beneath it a sheet of lead or felt. When placed in position and accurately levelled tighten the foundation bolts up evenly and gradually to avoid straining, and drawing the pump out of line. Move the piston backwards and forwards a few times and see that it is perfectly free, and that the stuffing box packing does not bind the rod. When the pump is in perfect alignment, the foundation bolts can be cemented in their places or be kept in position by pouring melted lead or sulphur round them. The steam pipes should pass into a chamber arranged with a trap to release the condensed water before passing into the steam chest. The exhaust pipe should be of ample size and as straight as possible to avoid back pressure. All steam and water joints should be carefully packed.

Starting a Steam Pump.—(1) See that the steam cylinder and working parts are well lubricated, and the pump and connections perfectly clean and free from obstructions; (2) See that the stuffing boxes and pump are properly packed; (3) Open the air cock, which is or should be provided in all steam pumps, to relieve the pump and passages from air; (4) Turn on the water from the priming pipe and fill the pump; (5) If pumping against pressure, close check valve on delivery pipe; (6) Open the steam cylinder cocks; (7) Before starting let the cylinder thoroughly warm, this is especially advisable with large pumps or in frosty weather; (8) Now turn on steam *gradually*, and when no more water is expelled from the cylinder close the cocks. Never stop or start a pump suddenly, and always run it at a slow speed for the first two or three minutes. In starting a pump it will sometimes refuse to force although in perfect working order; this may arise from the presence of air in the pump cylinder, which may be compressed by the plunger and not expelled, and may usually be obviated by providing an air cock and letting the pump run free for a time. By placing a check valve in the delivery pipe, the pump can at the same time be relieved from pressure, a waste delivery being provided which can be closed when the pump has commenced to work. In the case of a hand pump the air may generally be expelled by working the pump as fast as possible for a short time. When hand gear is fitted, it is a good plan to work a steam pump backwards and forwards a few times by hand, before turning on steam. If the pump is new or has been out of use for some time it may be necessary to charge the pump and suction pipe with water; this may be done through a pipe or hose, which can in many cases be conveniently connected with the delivery pipe. Straightway or other efficient stop valves for shutting off the steam or water in case of accidents should in all cases be fitted.

Speed of Steam Pumps.—It can hardly be denied that in practice it is found that a moderate piston speed gives the highest percentage of work. It is of course impossible to lay down a rule as to speeds, as they will vary with the pump, the nature of the duty, liquid pumped, &c. With direct acting and fly wheel steam pumps a piston speed of from 50 to 120 feet per minute will be found a fair margin for various duties, although a continuous boiler feeding pump, for instance, will sometimes run slower than this, a fire engine pump much faster. Single and multiple barrel pumps should run about 60 feet per minute, and boiler feed pumps about 45 feet per minute. It may be taken as a rule that the faster the speed of the pump the more perfect must be the working parts and connections to secure an effective result.

Stroke of Pumps.—The length of stroke of a pump is undoubtedly an important factor in its successful working, but must necessarily vary to a greater or less extent with the duty the pump has to perform. Speaking generally, the writer is distinctly in favour of long stroke pumps, as with the same diameter of piston the loss of water through the valves is practically the same, whether the stroke be long or short. A long stroke also possesses the advantage of having less frequent changes in the direction of the travel of the piston and flow of the water, a matter of considerable moment especially in large pumps, where the inertia of heavy weights has to be overcome. It will also be apparent that the frictional wear and tear, loss from clearance, &c., of pumps with a long stroke working at a moderate speed, will be appreciably less than pumps, whether direct-acting or crank and fly-wheel, with short strokes running at a high speed; short stroke pumps have, however, the advantage of occupying less space.

Air Chambers.—For equalising the flow of water and cushioning it, and for relieving the valves from severe shocks, air chambers have proved themselves extremely valuable, especially for high lifts and heavy pressures. Large air chambers will also often enable pumps to be worked at an increased speed. Air chambers—for heavy pressures especially—should be arranged so that they can be readily charged with air, to replace that absorbed by the water. No arbitrary rules can be made as regards the sizes or shape of air vessels, which vary according to the pressure from four to fourteen times the capacity of the barrel of the pump. In the case of steam fire engines air chambers are usually made of some twenty-five per cent. larger capacity than for ordinary pumps, and it may be taken as a rule that the greater the pressure the greater in proportion should be the area of the air vessel. To obviate the water being forced too high into the air chamber, and the consequent rapid absorption of the air by the water, it is advisable to make the chamber with as long a neck as may be convenient. Elastic air vessels have been tried to a limited extent, also apparatus for replenishing automatically the vessels with air, and these latter have proved themselves very useful for heavy pressures.

Care of Pumps.—A pump to do efficient and economical service should be as carefully looked after as a steam engine, all working parts kept clean, and where necessary well lubricated, stuffing boxes carefully packed, and the various valves periodically examined, cleaned, and adjusted.

Pounding in Pumps.—May arise from defects in the water cylinder, too sudden closing of the valves, &c., valves with too great a lift, broken valves or cage; by the steam valve not leading the piston, piston rings defective or broken, insufficient clearance, water in the cylinder, &c. In the case *of pumps* with a crank and fly-wheel it may arise from worn bearings, or connecting rod bearings not being keyed up tight enough, ridges or inequalities in the cylinder or guide bars, or the crank-shaft or cross-head being out of line. Pumps having springs fitted to the water valves may also pound through the springs becoming weak and losing their tension, or breaking. Occasionally pumps will pound badly when the suction pipes, &c., are perfectly air-tight, when the water supply is stopped; if desired this may often be modified or prevented by making a very minute hole in the suction pipe. Pumps will also pound if the duty is too heavy for them.

Piston Rod Packings for Steam Cylinders.—A great variety of materials are used for packing piston rods, such as hemp, spun yarn, French chalk, various preparations of asbestos, metallic packing, &c. For energetic friction the author has used with success asbestos yarn combined with soapstone, and this preparation requires very little lubrication. Ordinary cotton rope packing with an interior core of French chalk is liked by some, and it is easily applied. Several forms of metallic packing are extremely serviceable, but to secure success the rods must be in first class order and perfectly true, and the packing carefully fitted. Whatever kind of packing is used the box should not be filled too full and the gland screwed up equally and evenly all round, or packing may pinch the rod. causing undue friction, or, being unequally compressed, a leakage of steam. Packing should never be allowed to get old or hard, or it will very soon score or cut the rod, rendering it difficult to keep a steam-tight joint. Oils containing free or fatty acids should not be used as lubricants, as they decompose under the action of steam, and often glaze and harden the packing. Care should be taken that duplex pumps are packed on both sides alike.

Packing Pump Pistons.—Leather, layers of cotton and rubber, and metallic rings are usually employed for packing pump pistons. Leather of the finest quality only should be used, and as it swells a little if carefully fitted will make a very tight joint. Metallic rings of cast-iron, steel, and gun metal in a considerable variety of arrangements are used. Some of these are expanded by springs and other devices, but care must be taken that the expanding force is carefully adjusted, or a considerable unnecessary frictional loss may arise. For ordinary purposes a good deal may be said in favour of the old plan of a single broad ring of cast-iron carefully turned, and relying on its own expansion to keep a tight joint. If the cylinder is in good condition very little expansion on the rings is necessary, and if scored no amount of expansion will keep a tight joint. Whatever form of ring is used it should be very carefully turned and fitted, and the pump cylinder also kept in perfect order. If the combination cotton and rubber packing is used it is important that sufficient room is given for it to expand without causing too much friction, if not the driving power will be largely increased. For packing the stuffing boxes hemp gasket plaited tight, saturated with tallow, is largely used.

Fitting Cup Leathers and Valves.--The finest possible quality of ox-hide leather should be used for the above purposes. In the first place, it should be reduced to one exact thickness, and a hole bored through it to fit the centre bolt of mould; it should then be thoroughly softened, placed in the mould, and tightened up. It should be allowed to thoroughly set and afterwards be carefully pared or turned in a lathe with a leather knife, and when finished be well greased. The rim of the cup should be made of moderate depth only, as it is found in practice that chief wear on the cup is a narrow ring of leather where the cup touches the barrel, and a very wide ring is no advantage whatever and is more difficult to make.

Leathering Pistons of Hydraulic Pumps.—Pistons of hydraulic pumps should be arranged, as far as may be, so that the water pressure in working helps to keep the leathers tight. For small pistons and plungers a simple spiral leather packing is very serviceable; it consists of a strip of leather about quarter of an inch wide and is wrapped round the plunger four or five times; the leather should be pliable, chamfered at both ends, and wrapped tightly round the plunger so as to just fill tightly the groove provided for the purpose. If neatly done this packing will last a considerable time.

Working Pumps in Frosty Weather.—Open all drain cocks when leaving off work, and see that all water is drained from the steam cylinder, pump, pipes, and air chamber, and close the check valve in the delivery pipe. Before starting work examine the pump, valves, cocks, and connections carefully, and, if frozen, pour hot water on them till the ice is quite melted. Thoroughly warm the cylinder with steam before starting, open the drain cocks, and if possible work the pump for a few strokes by hand. See to the cylinder and other lubrication. Oil may be prevented freezing by mixing a little kerosene with it, and the water in the boiler by banking he fire.

Pumps "Sucking Wind."—Pumps should never be allowed suddenly to "suck wind," or a risk may be run —especially with direct acting pumps—of knocking the cylinder ends out.

How to Test the Pump of Portable or Traction Engines.*—*Test the pump occasionally* by opening the waste tap; if no water is expelled the pump is not working, either from there not being a vacuum, the packing or joints being out of order, the valves choked with dirt, or the pump hot. Before taking it to pieces place your hand tightly on the end of the waste-pipe, allowing the air to be discharged from the pump by the inward stroke of the plunger, but not allowing any air to re-enter during the outward stroke. If this has the desired effect in setting the pump to work, close the waste tap and the water will be forced into the boiler. If the pump gets hot pour cold water on it. If hot water continually issues from the waste cock, the probability is *the check valve nearest the boiler is choked*. In this case the steam must be blown off and the fire put out, the valve box cover must be taken off, and the dirt or obstruction that prevents the valve acting removed. If the suction or delivery valves are choked hot water will not pass through the waste cock; these valves may be examined when the engine is working, but should the defect not even then be discovered, the suction valves, delivery valves, and the packing of the plunger must be examined and the packing renewed, as the pump is probably drawing air; screw up and clean the union nut of the suction pipe, and make another trial. Occasionally a valve that has stuck may be released by a few sharp blows of a hammer on the outside of the clack cover. If a pump plunger is worn it will not act, at any rate satisfactorily, and should be seen to. In case it is necessary to take the pump to pieces, should there be no check valve fitted or it be choked, be sure that the water stop valve is closed or the boiler may be drained of water and an accident occur. If a valve has too much lift it is apt to stick, and should, therefore, be adjusted periodically as it wears. Feed pipes should in all cases be of ample size, owing to their liability to fur up. Bends in the suction or delivery pipes should be avoided. Take every precaution to prevent sand or grit getting into the feed water.

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* See "A Hand-book for Steam Users," by M. Powis Bale.

Steam Pumps not giving out reputed power.—Not a few pumps when in operation fail to give out their reputed effect; this may arise from a variety of causes, such as—(1) Badly proportioned or faulty design; (2) Suction or delivery pipes of too small diameter, or too many bends in pipes; (3) Want of air chamber; (4) Leak in piston, suction pipe, or want of retaining valve; (5) Inadequate supply of steam or steam throttled; (6) Air lodged in pump; (7) Pump valves not working properly, valves leaking or "dancing"—in the case of ball valves—and other reasons.

Causes of Pumps Failing.—Amongst the chief causes of pumps failing are the following—(1) Imperfect connections and air leakage in same; (2) Worn pistons or plungers, or leaky steam valves; (3) Worn water valves, or defective packings; (4) Dirt in steam or water valves or suction pipe; (5) Air in the pump chamber, compressed by the plunger but not removed, with heavy pressure on the force valve; (6) Pump hot or filled with vapour; (7) Too great a length of suction, too small or crooked force or suction pipe; (8) Too small an air or suction chamber; (9) Improperly set steam valves; (10) Improper type of pump or steam valves for the work to be done.

Testing Pumps.—In all cases where pumps have to be sent abroad they should be thoroughly tested under steam and water before being shipped, as it may prevent loss and annoyance when the pump may be many miles from skilled labour. They should if possible be tested under similar conditions to those in which they will have to work, but this is of course sometimes impracticable. In addition to running at high and normal speeds a good test for direct acting steam pumps is to run them very slowly, as in some cases they may become "centred," or stop, the momentum of the moving parts not being sufficient at a very slow speed to carry them through their stroke. The surest test as to efficiency is to measure the water pumped, being the only certain way that the amount of loss from "slip," leakage, &c., can be exactly ascertained. The suction and delivery valves can readily be tested under pressure when started and a leakage detected, but the loss through the return or "slip" of the water when the pump is in motion is very difficult to compute, it varying largely with the duty, type, and lift of the valve. Again, the amount of leakage of water past a piston can only be ascertained with any degree of certainty by taking off the cylinder end and subjecting it to the full water pressure, and even then the amount of leakage may differ when the pump is in motion.

Efficiency of Pumps.—It must always be borne in mind that the theoretical efficiency of pumps is much greater than their actual efficiency, or in other words, given the size and speed of a pump, it lifts theoretically a great deal more water than it does in actual practice. The modulus of efficiency of pumps working under ordinary conditions may be roughly stated as follows:—Common lift pumps, 50; centrifugal pumps, 50; ordinary lift and force pumps, 66; air pumps, 56 to 66; waterworks pumps, 80. Claudel gives the following per cent. of efficiency as taken from actual tests:—Fire engines working with hose, 35·8; pumps for drainage, 50 to 69; pumps for town water supply (single acting), 70 to 75. These figures must not however be considered as arbitrary, as the loss of efficiency will depend largely on the construction of the pump, its speed, duty, leakage of valves, imperfect filling of the water chamber, &c., and will vary considerably in different makes of pumps.

Lubrication of Working Parts.—A first class lubricant that will not develope fatty acids under the action of steam should be used for the steam cylinder, and the best quality procurable is in the end cheapest; the low grade inferior oils or tallow should not be used, as they soon gum up and often cause a great deal of trouble. Some engineers prefer suet to anything else for lubricating the steam cylinder. The author can recommend the addition of a little very finely powered plumbago or asbestos to the lubricant used, as it puts a face on the bearing surfaces and prevents the oil escaping so rapidly. The grease used for bearings should have a low melting point, and yet retain sufficient body that it will not readily escape from the rubbing surfaces. Sight feed lubricators can be recommended instead of grease cups for the steam cylinder, as they are much more economical and can be readily adjusted to supply the minimum amount of oil required for proper lubrication. It is a good plan to lubricate the cylinder before leaving off work to prevent sticking. For light high speed pumps sperm oil is good either by itself or mixed with a first class mineral oil; for heavier machinery, rape, olive, and neatsfoot oil, mixed with a little plumbago, are all good. For lubricating steam cylinders a preparation of asbestos and oil will be found very useful for high speed pumps and energetic friction.

Cooling Lubricating Compound for Heavy Bearings.—Tallow, 2 lb.; plumbago, 6 oz.; sugar of lead, 4 oz. Melt the tallow with gentle heat and add the other ingredients, stirring until cold.

For Lubricating Toothed Gearing.—Make a thin mixture of soft soap and black lead.

Notes on Designing Steam Pumps.—Although these pages were not written as a treatise on pump construction, a few general notes on some of the points to be borne in mind in designing may be of service to students and others into whose hands they may fall. Many of the ordinary instructions as regards machine design will hold good in the case of pumps, thus sudden contractions or enlargements in the pump or passages should be avoided. Every part subject to excessive strain should be cylindrical or partly cylindrical, this being the best form to withstand strain. Water valves and passages should be made as free and clear as possible, to give as little accommodation for the accumulation of air as may be, and to reduce the water friction on its passage through the pump. Rectangular shaped valve boxes and passages with elbows should in all cases be avoided, as these increase back pressure and working friction. The cylinder should be properly steam cushioned to allow the water valves to close themselves easily, and to give a smooth and steady motion to the pump with freedom from shock. If the steam valve be moved by means of a supplemental piston, the valve should be arranged with a positive motion near the end of the main piston stroke to avoid the possibility of the piston striking the cylinder end. The lineal clearance at each end of the cylinder of direct acting pumps should not exceed ten per cent. of the stroke. In designing the steam valves keep in mind the work the pump has to perform, if it will have to use dirty steam or be subject to rough wear select a simple form of valve, and avoid those of delicate mechanism, such as those requiring a number of levers, joints, internal tappets, small valves, links, &c., to operate, as they are likely to get out of order. Long steam passages should be avoided, and the steam applied as directly as possible on to its work. Whatever form of valve is used it is important that its action is absolutely certain, also that the speed of the pump is readily under control to ensure effective working. The steam and water valves, stuffing boxes, and various working parts should be designed so as to be readily accessible for adjustment or repairs. Small internal steam passages should be avoided, as they render joints more difficult to make and are liable to become choked. The clearance space in the pump should not be greater than is absolutely necessary. An air chamber of ample capacity should be fitted with a snifting valve to replenish the air which gradually becomes absorbed by the water passing through the pump. A gauge for showing the height of the water in the air chamber is also sometimes fitted. The type of water valves employed, their lift, and the material from which they are made, must be regulated by the nature of the duty they have to perform (see Pump Valves, &c.). The suction should be placed below the pump chamber, and the delivery as a rule above, and the pump and valves should be proportioned in strength to the head of water or pressure they have to pump against. In conclusion, it is important in designing pumps wherever possible that the areas of the pump and passages should be equalised as far as may be, so that the speed of the water through the pump may be even, and avoid the friction and jar of the different speeds arising from varying diameters, &c.

Working Parts of Pumps of Gun Metal.—The valves and working parts of pumps should be of gun metal when used for pumping beer, benzoline, bleaching liquor, hot water, oil, mine water, molasses, petroleum, salt water, spirits, sugar, syrups, tan liquor, and other liquids that affect iron. The piston rods also should either be made of gun metal or cased with it.

Making Enquiries from Manufacturers.—In writing or making enquiries from manufacturers it will save time and correspondence if the following details are given to enable them to judge as to the type and size of pump required:—(1) For what purpose is the pump to be used; (2) What is the maximum quantity of water or other liquid —in gallons—to be pumped per hour; (3) To what vertical height is the water to be raised, with height of suction and length of delivery pipes; (4) If suction and delivery pipes are already in existence give diameter and *number of bends* and also horizontal lengths; (5) What is the driving-power; if steam or compressed air are used give the average working pressure, and if they are brought from a distance say how far; (6) What is the liquid to be pumped, whether cold or hot, if hot state temperature; say whether clear, muddy, gritty, glutinous, alkaline, or acidulous, or containing any chemical or deleterious ingredient; (7) If pump is required for steam boiler feeding what is the highest pressure.

CHAPTER II.

PUMPS AND INJECTORS FOR FEEDING STEAM BOILERS.

Donkey Pumps, &c.—It need hardly be said that the selection of a reliable pump for feeding steam boilers is a matter of considerable moment. Donkey pumps, injectors, direct acting, fly-wheel, ram, and duplex pumps are all used for this purpose. A great deal has been written in favour of injectors over donkey pumps for boiler feeding, and *vice versâ*. I think in the case of large boilers, at any rate, the problem is best solved by using both, the one being held in reserve in case of breakdown, and thus preventing a whole establishment being laid idle. In the first place it is important, for the sake of economy, to avoid straining the boiler joints from unequal expansion, &c., and that the feed water be delivered into the boiler at a tolerably high temperature (see Injectors). Double acting pumps will deliver a steadier stream of water and are to be preferred to single acting pumps for boiler feeding, as the latter are more intermittent in their action. A boiler feeding pump should be capable of working either fast or slow, and at any pressure, so that the attendant may readily regulate an even supply of feed water and avoid flooding the boiler with a large quantity at one time. In the case of large engines separate pumps are preferable to one driven by the engine itself, as it dispenses with the necessity of starting the engine should water be required in the boiler when it is at rest. It is also often convenient to have one of the pumps arranged so that it can be worked by hand in case of necessity for filling or testing the boiler. Of course, with engines running at high speed separate pumps are absolutely necessary, as the water will not travel fast enough to follow the pump plunger. Pumps for feeding steam boilers should be capable of supplying two or three times the amount of water absolutely required. This enables the pump to be run at a moderate rate of speed, and by having the admission valve only partly open the feed may be made continuous, which is preferable to forcing large quantities of water into the boiler at one time. The feed pump should be placed near the boiler, as it saves long lengths of pipe, leakage, &c., and is more readily under the control of the attendant. A small direct acting pump may be used for boiler filling when steam is down by fitting a hand lever to the piston end.

In selecting a donkey pump, one with the crank placed central with the ram is generally to be preferred to avoid side strain. The fly-wheel should be of sufficient size and weight to regulate well. The plunger valves and glands should be of gun metal, the piston rods and pins of steel, and the joints case hardened. Where there are a number of boilers in use, plunger pumps arranged in sets and driven by gearing and cone pulleys are sometimes used, and are said to be regular boiler feeders and convenient to operate; but in these cases, to avoid accidents, additional supplementary steam driven pumps or injectors should always be fitted. These should be arranged with separate feed pipes and valves, so that should one line of piping burst or be disabled the boiler could still be fed through the other. It is very important that the water tank and pipes be kept clean and free from grit and sand, as nothing throws a pump out of order quicker than sand, by cutting the packing, plunger, valve, and seatings, and in some cases jamming the valve and entirely stopping its action. In case it is ever necessary to use water with sand in suspension it should be filtered or drawn through linen if possible, or some forms of injectors are perhaps to be preferred for this work to pumps.

Consumption of Feed Water by Steam Boilers.—High pressure or non-condensing engines, about 40 lb. of water per indicated horse-power per hour; condensing engines, 30 lb.; triple expansion engines, about 16 lb. Condensing engines require for injection water, about 5 gallons per nominal horse-power per minute.

Injectors for feeding Steam Boilers.—As elsewhere remarked much has been written as to the superiority of injectors over steam pumps as boiler feeders, and *vice versâ*, and although for general purposes we rather incline to the latter, it must we think be admitted that on the score of economy there is not very much to choose between them supposing them both to be the best of their class. Injectors have the advantage in low first cost, small space occupied, little wear and tear, and the loss of steam is not great, it being condensed by and returned to the boiler with the feed-water, at the same time greatly raising its temperature. Injectors are also comparatively noiseless and are not readily damaged by frost. Injectors are rather more delicate and not so certain in their action as a donkey pump, for instance, and are not so well adapted for rough usage or bad water, they also require a specially skilled man for repairs. With a donkey pump there is an increase in first cost, and in working a loss of steam through condensation, and unless the exhaust is utilised to warm the feed water there is a further and considerable loss; but pre-supposing live steam to be used in both cases (see Exhaust Injector), the duty performed by the donkey pump is considerably greater than the injector. Both injectors and pumps therefore having favourable points as boiler feeders, they can be well used in duplicate or as supplements one to the other in case of breakdowns. A well-made injector will lift water from 10 to 20 feet, and will force into the boiler from 15 lb. to 18 lb. of water with each pound of steam used; at the same time it will raise the temperature of cold water to about 100 deg. Fahr. whilst passing through it. Some injectors will force comparatively hot water, but the colder the water used the better will they work.

Fixing an Injector.—Injectors may usually be fixed either horizontally or vertically. All pipes should be of ample capacity without bends, and perfectly free, clean, and air-tight. It is a good plan to pass a jet of steam through them before fixing. A check valve should be fitted on the suction, and a back pressure or check valve on the delivery pipe near the boiler; this latter is particularly necessary so as to allow of the injector being taken to pieces for adjustment, and to prevent the water running out of the boiler. The water supply should be continuous and not hotter than 135 deg. Fahr. with low pressure, or 105 deg. Fahr. with the highest pressures.

If an injector is allowed to get hot it will not work, the reason of this being that the steam does not condense rapidly enough. Injectors will work at varying pressures, but usually best at high pressures of steam. The water tank should be fixed near the injector, and the water if possible filtered, or in lieu of this a very fine meshed sieve may be used to prevent grit, dirt, &c., entering the suction pipe, as it is found that even a small obstruction will sometimes stop its action. The injector should be fed with as dry steam as possible, the supply being regulated by a valve and the steam pipe covered with slag wool or other good non-conducting composition.

Starting an Injector.—In starting an ordinary lifting injector first turn on the water, then withdraw slightly the steam spindle and let steam pass through the instrument, this clears the nozzle and creates a partial vacuum, which causes the feed water to rise up the feed pipe into the injector. Now open fully the steam supply and water will be forced into the boiler. The temperature of the feed water has much to do in regulating the amount of steam pressure an injector will feed against. The hotter the feed water is the more water is necessary to produce the required vacuum, consequently, the velocity of the jet of steam, and therefore the power of forcing, is reduced in proportion. It is important, therefore, that the feed water is not allowed to get too hot, and that there is a second appliance for feeding the boiler should the injector cease to act from any cause. With the object of re-starting, should the jet of steam be broken and the injector stopped, injectors arranged to start themselves automatically have been introduced. Should the injector become hot, cool it with cold water. A sudden shock or vibration will sometimes stop an injector. The amount of water fed into the boiler may be increased by opening fully both the steam and water supplies. The injector nozzles must be kept exactly in line or the steam will strike the sides and its action be damaged. In fixing injectors we have seen the following arrangement carried out with very satisfactory results:—After the water has passed through the injector the delivery pipe to the boiler is made to lead through a larger tube containing exhaust steam, which raises the temperature of the feed water to some 200 deg. Fahr. before passing into the boiler. An overflow pipe should be provided with its end lead downwards into the water, and the steam and water supply should be capable of being readily regulated. Injectors will draw water from a considerable distance; they will work better, however, if the head of the feed water is placed slightly above the injector (see also Exhaust Injectors). It is important that all joints, pipes, &c., be made perfectly air-tight, and sheet asbestos can be recommended for this purpose in preference to red or white lead.

Diameter of Injector Nozzle.—Rankine gives the following rule for finding the diameter of the nozzle of an injector:—Sectional area of nozzle in square inches =

$$\frac{\text{Cubic feet per hour (gross) of feed water.}}{800\ \sqrt{\text{pressure in atmospheres.}}}$$

Hey's rule to ascertain the number of gallons delivered per hour into a boiler by an injector fed with steam from the same boiler, and working under ordinary conditions as regards temperature of feed water and height of lift, is as follows:—"Multiply the square of the diameter of the injector nozzle in millimetres by the *square root* of the pressure of the steam in pounds per square inch, and multiply the product by the constant number 2."

Exhaust Injectors.—Injectors constructed to use the exhaust steam from non-condensing engines, instead of live steam from the boiler, are now made and have proved themselves very useful and economical in feeding boilers working up to about 75 lb. pressure per square inch. The steam is taken from the ordinary exhaust pipe of the engine, and it is claimed that by the use of this form of injector, back pressure in the cylinder is reduced. The chief point of novelty in the construction of the exhaust injector is the employment of a split nozzle, through the medium of which it is made to re-start itself automatically should the jet of steam be broken and the injector accidentally stopped. This nozzle or combining cone is split longitudinally for more than half its length from the smaller end; one half hinges from a pin at its upper end, in such a manner that it hangs open when the injector is not at work and presents a large area for the water when turned on. When a vacuum is established the loose half of the nozzle is drawn inwards, and it acts precisely the same as if it were not split. If the supply of steam or water fails the flap falls away and presents a large opening for the water to pass through, the exhaust steam again enters, and condensation and the formation of a partial vacuum takes place, the nozzle is drawn inwards again, and the injector recommences to work. This automatic re-starting device can be applied to ordinary lifting injectors as well as exhaust, and should undoubtedly remove one of the chief objections urged against their use—viz., uncertainty of action. The method of fixing this *injector* to an engine is very simple. A branch pipe is taken from the exhaust pipe in any convenient place, it being best to make the connection through the top of the latter pipe; the exhaust is, therefore, not crippled in any way, but remains just as before, with the exception of the additional outlet to the injector, and therefore it is impossible that the back pressure should be increased by this application. The injector itself is fixed vertically, and there is a valve on the branch exhaust pipe so as to shut off steam when required. The end of the overflow pipe dips in water to prevent air entering the exhaust chamber. In the case of winding or other engines working for a few strokes only at a time, the branch pipe should be as short as possible, so that the injector may start at the first stroke of the engine. The feed water must be taken from a level above the injector and its temperature should not exceed 75 deg. Fahr. These injectors may be worked whilst the engine is standing, by connecting them directly with the boiler.

Making enquiries from Manufacturers of Injectors.—(1) State gallons of water required per hour; (2) Height of lift and the distance water has to be forced; (3) Average working pressure of steam; (4) Temperature of feed water.

Making enquiries from Manufacturers of Exhaust Injectors.—(1) State number and diameter of cylinders, with length of stroke, number of revolutions per minute, and point of cut off; (2) State average working pressure of steam in boiler, and if it is used for any other purpose than driving the engine; (3) Give number and sizes of boiler or boilers; (4) State kind of machinery driven by the engine.

Steam Water Elevators.—These operate through the suction or momentum obtained from a jet of steam, they will lift water up to about 20 feet, and force about one foot high for each pound of steam pressure used. They may be fixed either above or below the water to be lifted. The suction pipe must be perfectly air-tight and should be fitted with a strainer. Before starting the apparatus, the cock on the steam pipe should be slightly opened to allow of the condensed water to blow away. Although this class of lift necessarily uses a considerable amount of steam, they are cheap in first cost, and having no valves or moving parts of any kind are not liable to disarrangement. When working, the steam used is condensed by the rising water and passes away with it. These lifts are well adapted for filling tanks, and sometimes for temporary use, in sinking operations where an ordinary steam pump could not readily be used they can be suspended to a chain and raised or lowered as required; they can also be made useful in breweries, tanneries, chemical works, &c.

CHAPTER III.

HAND POWER PUMPS, &c.

Hand Power Pumps, &c.—These are made in a large variety of designs, either as lift pumps or lift and force pumps combined, and adapted for shallow or deep pumping, and to suit varying circumstances. Many of very rough and inferior construction are placed on the market; these, although low in first cost, are dear in the end. A really efficient pump should be made of good close-grained iron, have a bored barrel and gun metal valves; it is convenient to have these latter so arranged that when the handle is lifted to its full height, all water will escape from the pump, and obviate any chance of freezing. The fulcrum and lever should be adjustable to any desired point, and the valves be readily examined for adjustment or repairs. Pumps that are fixed at a distance from the well and have horizontal suction pipes should be fitted with retaining valves. The base of the pump should be connected to it by bolts and nuts instead of being screwed, as in the latter case the joint often rusts up and cannot be unscrewed without great difficulty. If the pumps are used for raising hot water especial care should be taken with *the packing.*

Hand Fire Pumps.—A reciprocating force pump worked by a handle and placed in a bucket is the simplest form for this purpose. The working parts should be of brass, and an air chamber be provided.

Hand Pumps for Well Sinking.—A wrought-iron lift pump, with a cast-iron barrel, will be found suited for this work. The suction pipe should be of wrought-iron made telescopically, and by lengthening the pump rod it may be used for increased depths. The rising main should be made of rather larger diameter than the barrel of the pump, so as to admit of the pump being drawn for repairs. By fitting long lever handles to it several men can be employed at the same time. When it is required to drive with a hand wheel, it can be done by bringing the pump rod through the top of the pump column, and attaching it to a slotted compensating lever, which is itself actuated by a crank attached to the hand wheel. Pump valves of the clack type, made large and free, are suitable. If there is a slight air leakage in a hand pump it may be sometimes got over by working the pump very fast for a short time, thus giving less time for the air to enter.

Chain Pumps.—These consist, briefly, of an endless revolving pitched chain carrying a series of discs—usually of iron. These descend into the water, and on their upward journey pass through a tube carrying with them a considerable quantity of water. Owing to their extreme simplicity they are particularly well suited for rough usage, such as lifting liquid manure, sewage, &c. They are unaffected by frost, and having no valves or delicate parts cannot easily be disarranged or broken. They can also be readily repaired and altered to suit different depths.

The back fixed barrel should be made slightly larger than the front, which will give less liability to the lifting discs fouling on their downward journey. They should have a clearance of from three-sixteenths to a quarter of an inch, and discs of chilled iron can be recommended. By hollowing the discs a little, making them wide on the edge and slightly rounded on the top, an excess of water is prevented from running back, and they may be run at a higher speed than is usual without splashing. To prevent splashing these pumps are often covered in. For Colonial use wrought-iron pipes and coverings can be recommended on account of their lightness and little liability to fracture. Chain pumps may be worked either by hand, steam, or other power.

The Syphon.—This simple instrument can often be made very serviceable in conveying liquid from one tank or vessel to another, provided that the second vessel is at a lower level than the first. The syphon consists simply of a bent tube, one end being placed in the water or liquid to be moved, and the other and longer end in the vessel which is to receive it. On exhausting the air from the pipe or filling it with water, the pressure of the atmosphere on the water in the full tank will force it through the pipe and into the second vessel till the water in it is raised to the same level as that in the first. The pressure of the atmosphere is not sufficient to force water through a syphon to a greater height than 33 feet, but it can, however, often be made very useful in breweries, distilleries, &c., and save much labour.

Water Lifts ("*The Noria*").—One of the simplest and most ancient forms of water lifts is known as the "Noria," and consists briefly of a series of buckets fastened to an endless chain which is wound round a drum by means of suitable gearing, and worked by hand, bullock, or horse power. This form of lift is still used considerably in India and the East. It requires little fixing, being simply placed on a stage over the water with the chain and buckets arranged to pass through it. When bullocks are used it is important that the gearing is speeded to suit them, as the pace at which they walk is considerably slower than horses or mules. If an engine is available this form of lift can be driven by steam by substituting a driving pulley for the horse gear or handles.

Test Pumps for Proving Mains, Boilers, &c.—For these purposes a ram pump worked by a lever is usually employed, but sometimes a pump with two pistons is used, the one piston being inserted into the other, the larger one being utilised for filling and the smaller for testing. Pumps for this work should be strongly made and fitted with a pressure gauge.

Pumps for Cleansing Gas Pipes.—For cleansing gas pipes, &c., a small force pump worked by a handle is usually employed; this is used to compress the air in a copper cylinder, which being suddenly released into the pipe clears it from obstructions.

Tube Wells.—During recent years tube wells have come very largely into use and proved themselves very valuable, especially for moderate supplies and depths. The spring is tapped through the medium of a steel-pointed wrought-iron tube, perforated at its lower end for a distance of one or more feet. The tube is sunk by blows from a monkey, falling on a clamp attached to the tube near the ground. It will be seen, therefore, that it cannot be used when hard rock, &c., has to be pierced. In sinking, the tube should be tested occasionally for water by means of a plumb-line, or a water-bearing strata may be passed inadvertently. When water is reached, a hand lever pump is attached to the head of the tube, and charged with water from the top. The water first raised will probably be dirty, from the earth which has penetrated the tube during sinking. This can generally be cleared by raising the pump handle to its full height a few times, thus opening the valves and allowing the water to run back down the pipe suddenly. It should be stopped by pumping before it has reached its level at the bottom of the tube, and this will cause the water to run in and out of the perforations at the bottom of the tube and clear them from obstructions. In sinking the tubes it is important that they are carefully jointed and the ends butt together, so that they drive solid. They should also be kept in an exactly vertical position in the centre of the tripod which is used for working the sinking monkey. The lengthening pipes are jointed by screwed sockets; these should be whiteleaded and screwed together as tight as possible with a pipe wrench. If a considerable quantity of water is required, several tubes are sometimes driven, coupled together at the top and connected to a large pump. When the water does not rise up the tube within, say, 25 feet of the pump, the working barrel with a foot valve must be fixed below the surface, say, about 10 or 15 feet from the water level.

Pumps for Domestic purposes.—In addition to the various forms of hand power pumps in large establishments, pumps driven by hot air or gas motors are used to a considerable extent. In country places and for occasional duty a good hot air motor will be found very useful, as it is readily managed, and, having no boiler, there is no risk of an explosion. The drawback hitherto to the use of hot air engines has arisen chiefly from particles of the coke used to heat the air being drawn up into the cylinder and grinding and cutting it away, and thus causing a leakage. This objection has been largely overcome in an engine of recent construction, by introducing between the retort and the cylinder a film or ring of compressed air, which prevents the gritty particles travelling upwards. For small powers there is no doubt that hot air motors can be worked with extreme economy, if carefully regulated and looked after. The author has had one of six-horse power running at his works for experimental purposes under the friction brake, in which the cost of fuel was less than one penny per horse power per hour. Another very useful form of motor, well adapted for domestic use, has also been introduced, in the shape of a simple form of vacuum engine, arranged to work with steam at atmospheric pressure, which renders it free from danger by explosion. The motive power in this case is produced by the condensation of the vapour given off by boiling water

Lifting Water by Hand from Wells.—For drawing water with buckets from deep wells wire rope can be used with advantage instead of chain, being much less in weight, and by the aid of suitable intermediate gear and a clip wheel arranged with a double row of clips converging, by intermediate pressure, to each other, and clipping the wire rope as it ascends and releasing it as it descends, a much greater quantity of water can be raised for the power expended *than with the* ordinary chain and windlass.

CHAPTER IV.

CENTRIFUGAL AND ROTARY PUMPS.

Centrifugal Pumps.—For lifting a large quantity of water to a moderate height, no other form of pump surpasses the centrifugal. Centrifugal pumps also possess the advantage of strength and simplicity of construction, they are also moderate in first cost, require little foundation, and are easily erected or repaired. A well designed and constructed centrifugal pump will discharge a larger volume of water, in proportion to the power used, than any other. Where applicable it is by far the best pump for contractors, irrigation, and drainage purposes, emptying docks, &c., as it is readily erected in awkward positions, and having no valves it is especially adapted for raising water containing foreign matter—it will pass stones, gravel, sand, leaves, &c., which would very soon choke ordinary forms of pumps. It will also work steadier than reciprocating pumps, being continuous in its action. It will lift well up to 20 feet, but it will discharge more water as the lift decreases, supposing of course that the speed of the pump be maintained; about 7 feet will be found an effective lift. If the pump can be fixed below the water level and the suction done away with altogether, its speed may be increased and a larger discharge secured; but excess of speed is not desirable, as the quantity of water discharged per revolution is lessened.

The working parts of the pump consist briefly of a series of curved blades or discs, mounted on a spindle and made to revolve in a cast-iron case, in a similar manner to a fan-blower. The revolution of these blades produces a partial vacuum in the case, which—aided by the pressure of the atmosphere—brings up the water. On the proper proportion, construction, and arrangement of these curved blades the effective working of the pump chiefly depends. To secure effective results, the blades must be arranged so that the water can enter the pump with as little friction or shock as possible, and with this object the blades are usually made curved and fixed almost tangentially to the periphery of the pump disc. It may be as well to observe that the loss of power through fluid friction in some pumps of faulty construction is very considerable, the water being churned and eddied round during its passage through the pump and the evenness of its flow disturbed. With the presumed object of reducing the friction of the water on its passage through the pump, in a recent design the suction is arranged to enter on one side only of the pump disc, consequently the water is not split up, as is the case with most pumps of this type, and by removing the centre of the pump disc, side thrust on the spindle is avoided. With the same object in view—viz., the reduction of friction, pumps are also arranged with a split or branched suction, and the water is made to enter the pump on either side of the pump disc directly opposite its centre, forming a balanced suction. In any case it is *very important that* the pressure of the water on the pump disc and impellers should be equalised as far as possible to avoid the side thrust on the spindle. In the latest practice the foundation plate for the pump is usually cast in one piece with the standard for bearings, which gives increased steadiness in working and allows the pump case to be removed without disturbing the suction pipe. The casing of the pump should be arranged so that one side may be taken off to allow of the inspection or cleaning of the pump disc, and hand holes fitted with bayonet-jointed covers placed on either side of the suction pipe, so that any obstruction may be readily removed. To dispense with the use of a foot valve and to save the trouble of charging the pump with water by hand, a small air exhauster is sometimes fitted and driven from the main pump disc spindle by a belt. A clack valve being fitted to the discharge pipe, the air is readily exhausted from the pump and pipes, and the pump charged with water. In smaller centrifugal pumps the main body of the pump is often attached by a quadrant bracket to the bed plate, which allows of it being swivelled round to any angle it may be desired to work at. This arrangement will be found very convenient for shore work or in awkward situations, at the same time the joints of the suction or discharge pipe need not be disturbed.

The curved blades or impellers should be made of steel or charcoal iron. Sometimes the blades are made of cast-iron and cast with the disc; this plan has the advantage of cheapness, but the blades are more liable to fracture, and it is much more difficult to balance the whole. Should the pump disc be even slightly out of balance, the bearings are rapidly worn away, and an uneven motion is produced on the water. The pump spindle should be of steel, fitted with a driving pulley of ample diameter and width, and an efficient method of lubricating the bearings secured. It will be found convenient to attach the suction pipe by means of a ball and socket joint, to permit of its being placed at any angle desired. Care must be taken that the pump is made to run at its proper speed, which will be in proportion to the height of the lift. By increasing the speed up to a certain point, either the discharge may be increased, or the water may be lifted to a higher level, but above 34 feet in height a plunger pump will generally give better results. Centrifugal pumps are usually driven by a belt, but steam or gas engines can be coupled either directly on to the pump shaft or worked through the medium of toothed gearing. Direct acting engines occupy little space, and are often convenient; but most of them consume a large amount of steam for the work done, the steam not being used expansively. For large pumps, and where great economy of fuel is necessary, compound and triple expansion engines with condensers have been used. Where gas is cheap, or the duty intermittent, gas engines are very useful as they can be started at any time without the delay of getting up steam. For irrigation purposes they are sometimes driven by a windmill or horse gear, and if mounted on wheels can be readily moved from place to place.

Rotary Pumps. — These are very useful pumps, particularly to brewers, distillers, wine and oil producers, gas works, &c., as with a connecting hose, liquids can be rapidly pumped from one cask or part of a building to another. Rotary, or what may be termed revolving piston pumps, in contra-distinction to direct acting pumps, have the advantage of not changing the direction of the flow of the liquid pumped with each stroke of the pump. They can be run at a high speed, and having no complex valves or leather packed pistons, cannot choke or readily get out of order. An excellent rotary pump for steam or hand power is now constructed: the interior of pump consists briefly of five parts, four parts being roller valves arranged to revolve on their seats, thus equalising the wear and rendering the pump more water-tight. We may add that water leakage is a defect found in most rotary pumps. Another somewhat novel form of rotary pump is now in use and appears to give excellent results. In this pump, the periphery of the internal drum is divided into four spaces, the two opposite being of the same area, and subject to the same pressure. The drum has four blades, which project radially from its centre at equal points, and two of these for one-quarter of a revolution are in contact with the wall of the cylinder, during which time they are exposed to the pressure on one side only, but during this time the only friction is that caused by the movement of the fluid; during the next quarter of a revolution these blades have an equal pressure on both sides. Each blade acts twice for a quarter of the distance at each revolution, consequently the four blades act for eight quarters or sweep out the water space twice during one revolution. It is claimed for this arrangement that the pressure is brought into an exact equilibrium on all moving parts, thus saving the loss by friction produced in rotary pumps when the pressure is allowed to act against one side of a drum and drive it against the bearing or abutment, which act as brake. Several forms of rotary pumps, with somewhat complicated arrangements of sliding pieces moving in contact with the outer casing of the pump are in use; these, if accurately made, work very well when new, but after running some time —especially if used with gritty water—difficulties arise in keeping the joints water-tight, and this form of pump should be avoided, at any rate, for rough and ready purposes. If, however, a rotary pump leaks, its efficiency is not so largely reduced as an ordinary pump would be, and in these cases the speed of the pump may be oftentimes increased with advantage. One of the best forms of rotary pump for rough work with which the author is acquainted, consists briefly in its interior of what may be termed a pair of very coarse toothed wheels or wings geared into each other. These teeth fit against the outer casing of the pump, and as they revolve past the water inlet they produce a partial vacuum, which is filled with water, and as the teeth or wings revolve this water is swept before them through the discharge pipe.

Belts for Driving Pumps.—Belts for driving centrifugal, rotary, and other pumps should be of ample width for the power they have to transmit, to avoid straining and the necessity of running an excessively tight belt, which means rapid deterioration of both belt and bearings. For driving centrifugal pumps out of doors, or in damp situations, vulcanised India-rubber or waterproof dressed cotton may be used. It is important that the belts are even in thickness and neatly joined to secure freedom from jump when running. They should be kept pliable, and a wide single belt is preferable to a narrow double. Double belts should in no case be run over small pulleys or they will soon crack. An application of tanners' dubbin, or a mixture of mutton fat and beeswax in equal parts will be found an *excellent* dressing for leather. Cotton driving belts may be rendered less hard by an application of linseed oil varnish. Tolerably long belts—say, 20 feet centres—are much preferable to short ones for driving, but care must be taken that they do not "swag" in working, or the bearings will soon cut out. Leather belts should be properly seasoned before being used, and cheap, spongy belts should be avoided, as they stretch unevenly, become twisted, and never run true, consequently a considerable amount of driving power is lost. The driving power of a belt may be increased to a certain point by increasing the tension, but if the adhesion at a moderate tension is found insufficient, increase the width of the belt or the size of the driven pulley. Avoid the use of resin and mixtures sold to increase the grip of the belt. If it is absolutely necessary to run at short centres, and the slip of the belt is excessive, have the pulleys covered with leather, or, in lieu of this, with several thicknesses of brown paper. In joining a leather belt with laces the best plan with which we are acquainted is to punch oval holes and place them zigzag across the belt, and not opposite to each other. Commence to lace in the centre of the belt, and lace outwards, leaving the ends to tie in the centre of the belt, and on the outside. Rivetted joints should not be used to run over small pulleys. India-rubber belts are damaged by coming in contact with mineral oils. It may be taken as a rough rule that for every horse-power transmitted by moderate sized leather belts, running at the rate of 400 to 500 feet per minute, it takes one inch width of belt, and that the horse-power increases in the ratio of this velocity.

CENTRIFUGAL PUMP FORMULÆ.

V = velocity of the periphery of disc or fan in feet per second.

H = height in feet to which water is to be raised, adding an allowance of 20 per cent. for friction.

R = revolution per minute of fan or disc.

C = circumference of fan in feet. G = gallons of water.

W = width of fan mouth (*i.e.*, at the periphery) in feet for a speed of flow for the water of 8 feet per second.

A = area of discharge pipe in square feet.

C' = circumference of fan in feet, minus the thickness of six blades.

E H P = effective horse-power required.

V may be calculated by any of the following formulæ:—

(1) $V = 1{\cdot}25\sqrt{64{\cdot}3 \times H}$. $V = 5{\cdot}50 + 550\sqrt{H}$.

(2) $V = 8\sqrt{H}$ in small fans to $9{\cdot}5\sqrt{H}$ in large.

(3) $V = 550 + 550\sqrt{H}$. V in this case equals feet per minute.

(4) $V = \frac{3}{2}\sqrt{2g.\ H}$. $g = 32{\cdot}2$. (5) $V = 8\sqrt{H} + K$. $K = 5$ to 10.

Formula 5 gives good results, varying the co-efficient K with the height of lift.

$$R = \frac{\{(8\sqrt{H}) + K\} \times 60}{C} \qquad C = \frac{\{8\sqrt{H}) + K\} \times 60}{R}$$

$$W = \frac{A}{C'}. \qquad E\,H\,P = \frac{G \times 10 \times H \times \frac{3}{2}}{33000}$$

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[*] For these *formulæ* the author is indebted to the "*Mechanical World* Office Book and Diary" (Emmott & Co.).

PROPORTIONS OF CENTRIFUGAL PUMPS.

Dia. of Discharge Pipe A.	Dia. of wrought-iron spindle.	Revolutions per minute.	Dia. of disc or fan in ins.	Discharge calculated for a head or lift of 20 ft.			Approx. effective horse-power of engine required	Approx. size of engine required with boiler pressure of 65 lbs.	
				Galls. per min.	Cub. ft. per min.	Tons per hour		Dia.	Stroke.
inch	in.							in.	in.
3	⅞	540	18	150	24	39·3	1¼	5¼	5
4	1	490	20	260	41·6	68·6	2⅛	5½	5
5	1¼	430	22½	410	65·6	108	4	5¾	5
6	1⅜	400	24	590	94·4	155·4	5½	7	6½
7	1½	375	26	800	128	210	7½	7	7
8	1⅝	350	28	1000	160	264	9	8	7
9	1¾	300	31½	1400	224	369·6	13	9	8
10	1⅞	285	34	1600	256	422·4	15	10	8
12	2	265	36	2300	368	607·2	21	10½	8
14	2¼	230	42	3200	512	844·8	29	12	10
16	2½	220	44	4000	640	1056	36	13	10
18	2¾	200	48	5200	832	1372·8	47	14	12
20	3	190	50	6600	1056	1742·4	60	16	14
24	3½	180	54	9100	1456	2402·4	83	18	14

The diameter of the fan varies from 1½ to 5 times the inlet diameter. The larger the fan the less number of revolutions it requires to make.

The speed of the water through the pipes should not much exceed 8 feet per second.

In many pumps the flow of water is greater (10 feet per second), but this is too high for good practice.

Example.—What size of pump is required to lift 4,000 gallons to a height of 15 feet?—

First find velocity of periphery of disc. $V = 8\sqrt{H} + K = 8\sqrt{15+3}$ feet for friction $+ 6 = 8\sqrt{18} + 6 = 39{\cdot}92$ feet per second, say 40 feet per second.

The diameter of the discharge pipe, at 8 feet per second flow of water, will equal $\frac{4000}{6{\cdot}2} = 640$ cubic feet. $\frac{640}{60} = 10{\cdot}66$ feet per second; then $\frac{10{\cdot}66}{8} = 1{\cdot}33$ square feet $= 16$

s diameter. If the disc is made 3 times the diameter of suction pipe = 48 inches, the number of revolutions will be = $\frac{40\times60}{12\cdot5}$ = 192 revolutions per minute. $W = \frac{A}{C'} = \frac{1\cdot33}{12\cdot2}$ = circumference of fan, minus 3 inches for thickness of blades = ·109 feet = say $1\frac{3}{8}$ inches for width of fan at circumference.

Hutton, in his "Works' Manager's Hand Book," gives the following as the horse-power required for centrifugal pumps:—

DIAMETER IN INCHES OF SUCTION AND DELIVERY PIPES.

	1	2	3	4	5	6	7	8
Quantity of water in gallons delivered per minute	16	50	100	200	300	500	700	800
Horse-power required for each foot in height which the water is lifted	·012	·025	·056	·085	·16	·25	·35	·40

	9	10	12	14	15	16	18
Quantity of water in gallons delivered per minute	1,000	1,500	2,000	2,500	3,000	3,500	4,200
Horse-power required for each foot in height which the water is lifted	·50	·75	1·	1·2	1·3	1·6	2·

CHAPTER V.

HYDRAULIC RAMS.

Hydraulic Rams.—Where there is a sufficient fall for raising by simple means a moderate amount of water, such as for the supply of mansions, farms, &c., the hydraulic ram has proved itself extremely useful. The principle on which it works is that a larger volume of water having a certain fall will force, under certain conditions, a smaller volume of water to a higher point than itself. In estimating the amount of water that can be raised and discharged, a general rule is to calculate that about one-seventh of the water used can be raised and discharged at a height five times as high as the fall, or one-fourteenth part may be discharged ten times as high as the fall, and so on in ratio, as the height of the fall and point of discharge is increased or diminished. The above calculation, of course presupposes a well-constructed ram. High or low falls may be used—say, from 10 feet to 18 inches, but above this height is not recommended, as the friction of the water passing through, and consequent wear and tear on the ram, becomes excessive. If any considerable quantity of water is required—say, about 1,500 gallons per hour—a fall of 8 to 10 feet will be found suitable. In these cases two smaller rams working into the same delivery pipe, in place of one large one, can often be used with advantage. Various improvements in the construction of hydraulic rams have been made of late, including the introduction of a piston and cylinder to assist the recoil of the water.* It is arranged as follows:—To the injection pipe or to the water chamber, between the air reserve and the water supply, is fitted a cylinder containing a piston acted upon by a spring, and connected by an opening with injection pipe or water chamber. When the water flows into the chamber and through the waste valve, and, having acquired a certain velocity, closes the waste valve, it forces up the delivery valve in the air vessel, at the same time forcing the piston up in the cylinder; some of the water enters the air vessel and compresses the air, which forces down the delivery valve and causes the water under it to recoil.

Hydraulic rams—which usually receive very little attention—should be simply and strongly designed and well fitted; the beat, delivery, and snifting valves should be made of gun metal, the strength of the air chamber should be tested, and all joints faced. Amongst the advantages of using an hydraulic ram may be mentioned that it is unaffected by the surplus or tail water, and will continue working even if completely flooded. It requires no lubrication or packing and will work day and night without attention.

In fixing a ram, care should be taken that both it and the pipes are protected from frost. This may be done by fixing them 3 feet or so below the ground. A suitable tail race must be provided for conveying away the waste water. A strainer should be fitted to keep leaves and rubbish out of the ram. Where a constant water supply is necessary, two rams, with duplicate sets of valves, can be recommended, as in case of repairs to one the other can be kept at work, and a partial supply maintained. The length of the supply or drive pipe can be varied from 25 feet to 200 feet, but a short one is to be preferred. It should be as straight as possible, and of a diameter suitable to the capacity of the ram. If bends are unavoidable they should be as long as possible in both the drive and delivery pipes. It must be borne in mind that the greater the length of the delivery pipe through which the water has to be conveyed, the greater the friction, and consequently more power or water is consumed in forcing.

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* See "*Steam and Machinery Management.*" By M. Powis Bale.

In regard to the efficiency of hydraulic rams. The proportion or percentage of the water delivered depends upon the two conditions of the problem—that is, first: The working head, or the vertical height from the surface of the water in the reservoir or spring, to the level of snifting valve; then, secondly, the total vertical height above the snifting valve at which the water is discharged. The largest quantity is when the working head is great and the delivery head low, and there is also always a certain proportion of height to head at which the effect is equalized, and at which the apparatus will be inoperative. For instance, with a working head of 2 feet, there would practically be no delivery above 40 feet, or, with a working head of 4 feet, water delivered at 80 feet. In fact, where there is a great difference between the two, only a very small percentage of water can be depended upon.

The accompanying table, taken from the *American*

Engineer, has been prepared to show the percentage of efficiency under various working heads (from 2 feet to 24 feet) and delivery at various elevations, commencing at 15 feet up to 100 feet, which can be used to determine the quantity of water possible to be utilised in any given case, for instance:—

A spring by actual measurement is found to flow a volume of 25 gallons per minute, and is so situated that a ram can be placed at a distance of 100 feet with a gradual descent of the drive pipe giving a vertical working head of 8 feet from the surface of the water at the spring to the level of snifting valve of ram. What is the amount of water that will be delivered at the following heights of, say, 21 feet, 35 feet, 50 feet, 80 feet, and 100 feet? By referring to the accompanying table we find:—

PERCENTAGE OF THE TOTAL AMOUNT OF WATER TAKEN FROM RESERVOIR, UNDER VARIOUS WORKING HEADS FROM 2 TO 24 FEET, AND DELIVERED AT ELEVATIONS ABOVE THE RAM FROM 15 TO 100 FEET.

ELEVATION OF DISCHARGE ABOVE DELIVERY VALVE AT RAM.

Working Head	15 feet.	18 feet.	21 feet.	24 feet.	27 feet.	30 feet.	35 feet.	40 feet.	45 feet.	50 feet.	60 feet.	70 feet.	80 feet.	90 feet.	100 feet.
2 feet ..	·0724	·0533	·0402	·0307	·0235	·0181	·0112	·0063	·0027	....	....	....	....	.....	....
3 ,, ..	·1327	·1020	·0807	·0651	·0530	·0441	·0326	·0243	·0181	·0132	·0063	·0017	....	....	....
4 ,, ..	·1960	·1535	·1234	·1020	·0854	·0724	·0560	·0441	·0348	·0281	·0180	·0112	·0063	·0027	....
5 ,, ..	·2614	·2068	·1686	·1404	·1189	·1020	·0807	·0652	·0533	·0441	·0307	·0217	·0150	·0099	·0063
6 ,, ..	·3282	·2614	·2146	·1800	·1535	·1327	·1063	·0870	·0724	·0608	·0441	·0325	·0243	·0180	·0132
7 ,, ..	·3960	·3170	2614	·2203	·1885	·1640	·1327	·1096	·0920	·0782	·0580	·0441	·0340	·0264	·0205
8 ,, ..	·4647	·3733	·3090	·2614	·2248	·1960	·1595	·1327	·1121	·0960	·0724	·0560	·0441	·0351	·0281
9 ,, ..	·5341	·4303	·3572	·3030	·2614	·2285	·1868	·1561	·1327	·1142	·0870	·0682	·0545	·0441	·0360
10 ,, ..	·6040	·4877	·4058	·3450	·2984	·2614	·2145	·1800	·1535	·1327	·1020	·0807	·0651	·0533	·0441
11 ,, ..	·6745	·5459	·4549	·3874	·3357	·2947	·2425	·2041	·1746	1514	·1172	·0934	·0760	·0627	·0524
12 ,, ..	·7453	·6040	·5043	·4302	·3733	·3282	·2708	·2285	·1960	·1704	·1327	·1063	·0870	·0723	·0608
13 ,, ..	·8166	·6627	·5540	·4732	·4112	·3620	·2994	·2532	·2177	·1896	·1483	·1194	·0983	·0821	·0694
14 ,, ..	·8881	·7217	·6040	·5166	·4494	·3960	·3282	·2780	·2395	·2090	·1640	·1327	·1096	·0920	·0782
15 ,, ..	·9600	·7809	·6543	·5601	·4877	·4303	·3572	·3030	·2614	·2285	·1800	·1460	·1211	·1020	·0870
16 ,, ..	....	·8404	·7048	·6040	·5263	·4647	·3863	·3282	·2835	·2482	·1960	·1595	·1327	·1121	·0960
17 ,, ..	....	·9001	·7555	·6480	·5650	·4993	·4157	·3535	·3058	·2680	·2123	·1731	·1444	·1223	·1050
18 ,, ..	....	·9600	·8064	·6921	·6040	·5341	·4451	·3790	·3282	·2880	·2286	·1868	·1561	·1327	·1142
19 ,, ..	....	....	·8574	·7364	·6430	·5690	·4746	·4046	·3507	·3081	·2449	·2006	·1680	·1430	·1262
20 ,, ..	....	....	·9086	·7808	·6823	·6040	·5042	·4303	·3733	·3282	·2614	·2145	·1800	·1535	·1327
21 ,, ..	....	....	·9600	·8254	·7217	·6392	·5340	·4561	·3960	·3486	·2780	·2286	·1920	·1640	·1420
22 ,, ..	....	....	....	·8701	·7612	·6745	·5640	·4820	·4188	·3688	·2947	·2425	·2041	·1746	·1514
23 ,, ..	....	....	....	·9150	·8007	·7098	·5940	·5080	·4417	·3892	·3114	·2567	·2163	·1853	·1609
24 ,, ..	....	....	....	·9600	·8404	·7453	·6241	·5341	·4657	·4097	·3282	·2708	·2085	·1960	·1704

The co-efficient for 8 feet head and 21 feet discharge $= \cdot 3090 \times 25 = 7\frac{3}{4}$ gallons.

The co-efficient for 8 feet head and 35 feet discharge $= \cdot 1595 \times 25 = 4$ gallons.

The co-efficient for 8 feet head and 50 feet discharge $= \cdot 0960 \times 25 = 2\frac{1}{3}$ gallons.

The co-efficient for 8 feet head and 80 feet discharge $= \cdot 0441 \times 25 = 1$ gallon.

The co-efficient for 8 feet head and 100 feet discharge $= \cdot 0281 \times 25 = \frac{7}{10}$ gallons.

Or take the same volume of 25 gallons from the spring under a working head of 15 feet and 100 feet discharge $= \cdot 0870 \times 25 = 2\frac{1}{8}$ gallons; a working head of 22 feet and 70 feet discharge $= \cdot 2425 = 6$ gallons, and so on through all the various changes.

These proportions will be modified by the diameter and length of the discharge pipe, as the friction will re-act against the effect of the ram, so that where this pipe is of considerable length, the proper allowance must be made for the *friction head*, and it is also best to give a sufficient length to the drive pipe from the reservoir to ram, so that the water in it is not forced back by the re-action into the spring when the snifting valve closes. This is particularly the case with low heads. As a general rule, the area of the discharge should be from one-quarter to one-third that of the drive pipe, and in deciding on the size of ram judgment should be used in determining the proper amount of working head, as it is best to only use sufficient to deliver the quantity required, and not overload the ram.

CHAPTER VI.

PUMPS FOR SPECIFIC DUTIES.

Acid Pumps.—For pumping acids single-acting bucket or plunger pumps are usually employed, but sometimes pressure is put on the acid in a chamber or closed vessel, and it is forced through a pipe placed at the bottom of the chamber. For lifting acids pumps are made of glass, stoneware, iron lined with ebonite, lead, &c., also of porcelain. To withstand hydrochloric and other strong acids, which rapidly affect iron and other metals, the pump is lined or made with a patent white metal alloy. Glass barrel pumps can be recommended for pumping most acids, ammoniacal liquor in bleach works, for use in chemical works, &c. The barrel is made of plate glass, is bored and polished and mounted in fittings of gun metal, lead, or iron, according to the nature of the liquid it is used on. India-rubber valves are usually employed. Asbestos can be recommended for packing the glands, &c., of all pumps used with acids, as it is unaffected by them. Pumps with *movable* cylinders lined with porcelain are also used for *his work.*

Air Pumps.—Air pumps may be roughly divided into four classes—viz., bucket, piston, plunger, and rotary; these are made in a variety of types, both single and double acting, to suit varying duties. When employed for exhausting, air lift pumps are used; for compressing, force pumps, often combined with engines. In recent practice we have seen air pump valves made from an elastic sheet of phosphor-bronze acting remarkably well; India-rubber and vulcanized fibre are also used (see Air and Circulating Pumps). Phosphor-bronze can be generally recommended for valves, as it is unaffected by mineral oils, the hottest water, and is very little affected by acids.

Air Pumps for Pneumatic Tubes.—For this purpose, where letters, &c., are propelled by compressed air and withdrawn by exhaustion, double acting air compressing and vacuum pumps are employed, so arranged that they may be used for compressing or for vacuum as may be desired.

Air and Circulating Pumps for Surface Condensers.—In recent marine practice it has become the fashion to use independent air and circulating pumps instead of those driven directly from the engine, which in many cases ran at too high a speed for economical working, and were thus also more liable to breakdowns or disarrangement. A convenient arrangement lately introduced combines both pumps in one apparatus, the pumps being placed tandem fashion, and the same steam cylinder employed to drive both the air pump to form the vacuum and the pump for circulating the water. Another improvement in this connection consists in keeping the piston of the air pump submerged, and drawing in and expelling the vapour through alternate pulsation of water columns on each of the piston. The air pump valves are balanced connected mechanically with the valve mechanism of steam cylinder, thus ensuring a steady and positive ac Air pumps for this work are generally made double a and fitted with water jacket. In the best practice circulating pump barrels are either made of or lined gun metal, the plungers and valve seats of gun metal the pump rod cased with brass, with valves of phos bronze, gun metal, pure rubber, or vulcanized India-rubber, however, has given way somewhat lat in favour of vulcanized fibre, which can be used in th sheets, and is not readily affected by mineral oils water, &c. To avoid using power to waste it is a plan to arrange that the pump may be started a vacuum formed before starting the main engine, and it can be driven at varying speeds, so that, should the a heavy load on the engine, its speed may be incre or decreased in the case of a light load. Again temperature of the injection water in summer and w will sometimes vary thirty or forty degrees; and if pump be driven at the same speed summer and winte secure a good vacuum in the summer it would be nece to use a larger pump than would be required in the wi and the power consumed in driving the larger pump w be wasted, another point in favour of using pu independent of the main engine. Centrifugal pu driven by a separate engine are also used as circul pumps for surface condensers.

Pumps for Breweries.—Various forms of direct a *pumps,* treble-barrel, bucket, and plunger pumps, *small* enamelled rotary pumps are usually employe breweries. All the working parts and valves should be made of gun metal, India-rubber and leather are unsuitable; although the former is occasionally used. The valves and water passages should be as large as possible, to allow of pumping thick beer, &c. For raising hot wort much suction cannot be employed owing to the difficulty of obtaining a vacuum through the steam constantly rising from the water. Piston pumps are generally to be preferred to plunger pumps for brewery purposes.

Wine Pumps for Vineyard, Wine Cellars, &c.—Enamelled rotary pumps and bucket pumps made of gun metal are chiefly employed for this work. Flexible suction and delivery pipes are used, and when employed in emptying casks by fitting a tapering attachment to the suction, it may be made to fit any sized bung-hole. For agitating and mixing spirits, wines, &c., a centrifugal pump is often used.

Colonial Pumps.—In the Colonies or countries where skilled labour is not readily attainable, a strong and simple form of pump readily repaired or adjusted should be chosen. Hand pumps, chain pumps, pulley or geared pumps, centrifugal and fly-wheel steam pumps will be found simple and serviceable, and not too expensive. Steam pumps with delicate valve gear, which is always more or less liable to disarrangement, should be avoided. Wherever possible the parts of steam pumps for Colonial use should be sub-divided as far as may be, so that in the event of fracture it is not necessary to replace the whole water end of the pump, cases of which we have seen. Suction and other pipes of wrought-iron are the best, as they are light and can be readily cut and jointed. Amongst steam pumps, fly-wheel pumps driven by a crank and fitted with ordinary flat steam valves operated by an eccentric, as in a steam engine, can be recommended, as they do not require very skilled attention, are certain in their action, are readily repaired, and will stand a considerable amount of rough usage without getting out of order. (See also Centrifugal, Chain, and Geared Pumps.)

Contractors' Pumps.—Centrifugal and chain pumps can be recommended for ordinary purposes, and bucket pumps or steam lifters for light sinking work. For hand purposes wrought-iron pumps and pipes are to be preferred, as they are lighter and less liable to break; they should be fitted with a telescopic suction pipe to suit variable depths. For contractors' purposes, where the usage is generally very rough, and the water not of the cleanest, the complex or delicate forms of direct acting steam pumps should not be selected. Where, however, the water is clean, and a large quantity has to be raised a considerable height, steam pumps are of great value, as this duty cannot be performed by either centrifugal or chain pumps. Where space is available a long stroke horizontal crank and fly-wheel pump can be recommended. (See Centrifugal and Chain Pumps, &c.)

Creosote Pumps.—For the purpose of forcing creosote into chambers for preserving timber, a strong double force pump with cast-iron barrels and gun metal plungers can be used; clack or spindle valves of gun-metal, and arranged with a low lift, are suitable for the pump. As considerable pressure is often required to force the creosote into the wood, it is advisable that a safety valve be fitted to the chamber. Although we recommend the above construction for forcing purposes, for simple pumping of creosote, pumps are often made of cast-iron.

Fire-Engine Pumps.—For fire-engine purposes, direct double acting bucket and plunger pumps made of gun metal are usually employed. There is generally one steam and one water cylinder, but for large sizes double or treble pumps with the same number of cylinders are often used. The object of fire-engine pumps is to force a large head of water to a considerable height and at a great velocity; for this purpose a pump with a tolerably long stroke and moderate piston speed can be recommended, as it allows the pump to fill better at every stroke and the valves to close without violent shock. The valves and passages must be clear, and copper air vessels are usually fitted to both suction and delivery pipes, and it is important that these are kept well supplied with air. It is, of course, necessary that the boiler working these pumps is constructed so as to generate steam as rapidly as possible; with this object in view water-tube boilers are largely employed, the tubes being allowed to hang down into the fire-box and be exposed to the direct action of the fire. With this arrangement steam can be raised to 100 lb. pressure in about ten minutes. The pump should not be attached to the boiler. For floating fire-pumps long stroke pumps are usually employed.

Fixed Steam Fire Pumps.—In many large establishments containing great quantities of valuable property it has become the practice of late years to erect a stationary steam pump to be used as a fire-engine in cases of emergency. For this purpose a long stroke double ram pump can be recommended, as at a moderate rate of speed and with moderate boiler and water pressure jets may readily be thrown 150 feet high and upwards. The pump is usually fixed in a position where the different points of the building may be readily commanded. The areas of the valves and water passages of the pump should be ample, so that when the pump is running at a high speed it should be filled as near as may be with water at each stroke. For mansions, &c., double barrel hand pumps, worked by levers and cross-handles, make a serviceable fire pump.

Pumps for Farm purposes.—In addition to the ordinary hand lift and force pumps, a very useful form of pump for farm purposes is a vertical double barrel worked by a double lever with socketed ends. It is usually mounted on a travelling carriage, and can be used with advantage as a fire pump. Hose is employed for suction and delivery, and is connected to the pump with gun metal unions.

Pumps for Brickyards.—Single, double, or treble barrel pumps, mounted on frame, with crankshaft and fast and loose pulleys or gearing, or, in lieu of gearing, chain wheels to drive by chain are largely employed. A large single barrel pump is to be preferred to a smaller double, as there is less liability to stoppage from the valves becoming choked with mud or sand. Chain and rotary pumps are also very useful for this class of work, and they possess the advantage of being without valves and packing, and cannot well be damaged *by frost.*

Pumps for use where fuel is expensive.—The selection of these will of course depend greatly on the duty to be performed. For large water supply compound condensing pumping engines are generally employed Compound condensing duplex pumps can also be recommended for economy of working, and if properly constructed they will give a steady pressure of water without undue strain. The steam cylinder should be jacketed and lagged, the steam passages made as short as possible, and a free exit given to the exhaust to avoid back pressure. For some duties a small steam engine with a pump driven by gearing can be used with advantage, in these cases the engine should be fitted with expansion gear, and if the feed water is fairly pure a multitubular boiler used.

Pumps for High-pressure Steam.—Where pumps are used with steam, say, above 100 lb. pressure per square inch, they should be made of special proportions and increased strength. In these cases compound steam pumps can generally be used with advantage.

Pumps for Gas Works.—Single and double acting piston pumps, double acting plunger pumps, and rotary pumps are those chiefly employed in gas works. For pumping tar a long stroke pump running at a slow speed is suitable. The suction should be made as short as possible, and the working barrel, passages, and pipes must be large and free, and without bends and angles. The valves should be of the butterfly or flap type, of large area, and they will require a considerably higher lift than if used for water. The pump and all working parts should be of cast-iron, the rod however may be of steel or wrought-iron, cased with cast, as tar has less action on it. The pump should run at a slow speed. If a pump is required to pump tar and ammoniacal liquor at the same time, double pumps are sometimes employed, a single steam cylinder being placed between them and working both. For pumping gas, rotary pumps (see p. 53) and hand syphon pumps are chiefly used, these latter are made in copper or iron, with metal valves.

Glass Barrel Pumps.—These are considerably used for lifting acids, ammoniacal liquor, paper pulp, bleach, vinegar, hot wort, &c. (see Acid Pumps). Iron pumps lined with vulcanite are also employed for lifting these liquids.

Geared Pumps.—Something can be said in favour of tooth geared pumps for heavy pressures, contractors' purposes, drainage, &c. They may be geared directly to the engine, be driven by belt or wire rope—this latter plan often rendering it very suitable for use in quarries, &c. Through the medium of gearing, the engine can be arranged to run at a sufficient speed to secure an economical consumption of steam without running the pump at too high a speed to ensure the best results. It should never be forgotten that if a pump is run at a very high speed it fails to fill itself at each stroke, a very considerable loss in effect being the result. It is important that the gearing is carefully proportioned, fitted, and speeded to reduce the friction and noise of working to the lowest limit. Hard wood gearing, if very carefully pitched and finished, will work very easily and without jar. Geared pumps possess the advantage of being positive in their action, and of not slipping under heavy pressures.

Pumping Hot Water. — There is a considerable difficulty in lifting hot water, this is owing to the steamy vapour given off from it, which fills the pump barrel and suction pipe, destroying the vacuum and preventing the hot water entering. In these cases the source of supply should be placed at a higher level than the pump and the water allowed to run into it by its own gravity. The pump should be worked at a moderate rate ot speed, and have large valves arranged with very small lifts. In lieu of one large valve several small ones may be used and a lower lift be obtained. The author has used gun metal ball valves for this purpose with advantage. Gun metal clack valves are also used. If it is necessary to have a short suction, the pump should be designed so that the vapour arising from the hot water should be expelled as far as possible at each stroke, and in addition to this a pet cock should be fitted to let the steam out of the pump. If the pump gets hot cool it with cold water.

Hydraulic Force Pumps.—Double acting, plunger, duplex, and three-throw pumps are used for supplying hydraulic machinery, accumulators, presses, &c. As these pumps are sometimes required to force against a pressure of several thousand pounds per square inch, they should be especially designed for this work, with increased strength of parts, area of bearing surfaces, &c. Steel should be used for piston rods and the very best material and workmanship employed throughout. Pumps can be arranged to stop automatically when a maximum pressure is reached, but they should in addition be fitted with a relief valve. Exterior packed pumps can be recommended for this duty, as the packing can be readily adjusted or renewed in case of leakage. Pumps for supplying hydraulic machinery are sometimes arranged in pairs, the first to work tolerably fast to a certain pressure, when it stops, the remainder of the work being completed by the second pump working at a slower speed. Long stroke pumps are generally preferred for this class of work. Where great pressure is required gear driven pumps are often used owing to their positive action, and where only one or two are required they can often be conveniently driven by belt from a shaft.

Pumps for Irrigation.—Chain, Noria, Persian wheels, centrifugal, and, under certain circumstances, steam pumps are used for irrigation purposes. Where steam is not available horizontal double-acting bucket or plunger pumps, driven by horse or bullock gear, will be found very useful. They should be strongly and carefully made to withstand rough usage, and they can be mounted on wheels with advantage. In lieu of the ordinary horse or bullock power toothed gearing, a pump is now made in which direct motion is given to the pump plunger through the medium of a vertical shaft and horizontal crank, the pole for horse being attached to the vertical shaft and giving motion to it. Although this necessarily gives a slow piston speed, a better vacuum is obtained, and as the pump is usually of large bore a good deal of water may be raised. Persian or Chinese wheels are practically water wheels with iron buckets attached to their peripheries. They are largely used in the East for irrigating purposes (see also Chain, Centrifugal, &c., pumps). Where there is a river, steam pumps may be advantageously placed on a barge, and moved from place to place as required, and by means of hose a large tract of land can be reached.

Pumps Driven by Windmills for Irrigation, &c.—For irrigation, drainage, supplying farms, &c., with water, pumps driven by windmills can often be used with advantage, especially in the Colonies and remote districts where steam power is not readily available. For this purpose a double action force pump can be recommended, but a common lift pump is sometimes used. The pump should be of ample size in water way and passages, to obviate, as far as possible, choking from leaves, &c. After the first outlay for a windmill the cost of maintenance is very low, as it requires little attention, and, given a wind, it has the advantage of working both day and night. As regards the windmill, what is known as a self regulating sectional mill can be recommended in preference to a solid wheel mill, as it is more even in its speed, and in case of storms it can be arranged to coil itself automatically and cease from working, whilst a solid mill may run away and break the pump or be blown away altogether. In some windmills of improved construction the speed of the mill is governed by a centrifugal governor through the medium of a series of regulating weights, the size of the weights being changed according to the number of revolutions required. By means of a tail sail the mill can be made to always head to the wind automatically.

Pumps for Low Services.—In cases where water has only to be pumped to a moderate height by a steam pump the water plungers can be increased in diameter and made nearly or quite the size of the steam pistons, and thus the capacity of the pump for this especial duty can be largely increased. Under these circumstances, however, it is necessary to use another pump for feeding the steam boiler employed.

Screw Pumps for Low Lifts.—This form of pump is used to a limited extent for low lifts. They can be roughly and cheaply made, but the duty given out is very low and they have generally given place to other forms.

Pumps in Paper Mills.—For lifting paper pulp various forms of lift pumps are used, also treble force pumps. The pumps may be of iron, with gun metal working parts, valves, &c., as free as possible. Glass barrel pumps are also used.

Pumps for Petroleum Wells.—Very long stroke lift and force pumps, somewhat similar to deep well pumps, are generally employed for this work; these are driven by steam, or in sinking usually by hand, through the medium of a T or bob lever. The pump barrels and working parts should be of gun metal.

Pumps for Oil-pipe lines.—Two steam cylinders, each driving two double-acting plunger pumps, are suitable for this duty, as they are more free from shock and concussion than single cylinder or crank and fly-wheel pumps.

Pumps for Bore Holes.—For this purpose a vertical single barrel pump is usually employed, with suction and rising main pipes of wrought-iron. The pipe joints should be made flush both inside and out, and in equal lengths to the pump, so that they may be readily lengthened as the sinking proceeds. The pump rods can either be screwed together or joined with sockets.

Pumping Sandy or Gravelly Water.—No form of pump which has close-fitting pistons or joints in contact with the water should be used for this purpose. Centrifugal, rotary, chain, or pulsometer pumps are the best where they can be employed. If it is necessary to use a steam pump the water valve box should in all cases be recessed round the seat of the valve, and a blow-off cock fitted to relieve the valve of any impurities that may accumulate. Mitre or puppet valves should not be used, as they are very liable to clog; ball or clack valves are to be preferred. Steam pumps are now constructed especially adapted for raising muddy and sandy water in which both the pump valves and seats are made removable, so that they may be readily taken out, cleaned, and adjusted. As with sandy water the wear on the valves is often considerable this arrangement should prove itself serviceable. The water ways should in all cases be as free as possible.

Sewage and Sludge Pumps.—If sewage or sludge is pumped by steam, a long stroke plunger pump is generally to be preferred to a piston pump for this duty, but many large single acting lift pumps are also in use. It is important that the liquid has as few reversals of its flow as possible, and that there be no complications in the passages or corners, where the sewage can accumulate. The valves should be as large and free as possible, and readily examined; sometimes for this work the valve seats are made movable as well as the valves. Wrought-iron clack valves with leather seats are used for sewage purposes, and also double beat valves. Sewage lift pumps are often made of cast-iron, with leather buckets and valves, the clacks of leather weighted with iron plates. Where *the lift is low*, centrifugal pumps can be used with great advantage for this work; in some of recent construction so employed, foot valves to the suction pipes were dispensed with, but sluice valves were fitted to the delivery pipes and automatic weighted flaps at the ends of the delivery pipes. The pumps were filled through the medium of a steam exhauster, which created a vacuum in a standpipe to which the various pumps were connected. Hydraulic pumps worked by accumulators have also been introduced for this work.

Pumps for Sinking Purposes.—Pumps for this work should take up little room in the shaft, and be not over cumbersome. Vertical double acting pumps are very useful for this purpose, as they can be made to work suspended from a chain, which is a great convenience, as they can be readily raised when a shot is fired and lowered when the water is pumped out. They can be worked either by steam, compressed air, or through adjustable rods—in this latter case, to keep the pump to a uniform speed, and in case of breakage of rods, governor gear can be fitted with advantage. The author prefers the use of steam or compressed air, but care must be taken to cover the pipes to prevent both condensation and the surface water coming in contact with them. This may appear a simple matter, but it has been found otherwise by us in several cases where there was a great deal of surface water. What is required is a material that is not affected by the heat of the steam pipe on the inside or by the water on the outside. The best plan the writer is at present acquainted with is to cover the pipe with slag wool, and either box it in or wrap it round with a waterproof covering. This is a somewhat troublesome proceeding, and if a readily applied covering fulfilling the above conditions was produced it should find a good sale. Pumps used for this class of work should be of simple construction and certain in their action, owing to the trouble and difficulty of repairs. If water has to be raised to a considerable height a retaining valve should be fitted in the lower part of the rising main, and a foot valve at the base of the suction pipe. Pumps of the pulsometer type are useful for sinking purposes, as they are low in first cost, have practically no working parts—one ball valve only, with the usual suction and delivery valves being used—they are therefore not liable to disarrangement. They take little room and will force up to eighty feet high. They possess the drawback, however, of using a good deal of steam.

Pulsometer Pumps.—This form of pump or water lift has proved itself very useful for rough work and difficult situations, in quarries, shafts, &c., as it can be worked suspended by a chain, and readily raised or lowered as may be required. It consists, briefly, of two pear-shaped vessels cast together, the necks terminating in one chamber, wherein two valve seats are arranged, with one ball valve which oscillates between them. Air chambers, suction and delivery valves are also fitted. When the pump is charged with water, steam is admitted, and pressing on the surface of the water in one chamber, forces it through the delivery valve into the delivery pipe. When the steam reaches the opening leading to the discharge it comes in contact with the water in the pipes and is immediately condensed, forming a vacuum in the chamber just emptied of water. This vacuum draws the ball over to the second or opposite seat to which it previously occupied, and prevents for the time the further admission of steam. To fill the vacuum formed, water rises through the suction-pipe and fills the empty chamber—this operation is repeated again and again, and with such rapidity that a nearly continuous stream of water is forced through the delivery pipe. Air cocks are fitted to the pump and air chambers, and by opening or closing these the rapidity with which the pump chambers are filled with water can be regulated according to the duty. The suction and delivery chambers are fitted with removable covers, giving ready access to the valves for cleaning or adjustment. There being practically no moving parts in this pump, wear is reduced to a minimum, and very little attention is required, and sand, gravel, pebbles, &c., will readily pass through without damaging or clogging the valves, a matter often of great importance in sinking and similar operations.

Single, Double, and Three-Throw Pumps for Deep Wells.—Vertical barrel pumps of various forms and combinations are largely used for deep wells. They are worked by rods actuated by suitable gearing driven by hand, horse, gas, or steam power. Owing to the difficulty of fixing and consequent repairs, pumps of the very best construction should be selected for this duty. The pump barrel, suction bucket, head valves and seatings, and stuffing-box glands can be made of gun metal with advantage. In the case of the larger sizes the pump barrel may be gun metal lined. In some of the best pumps of this class the bucket rods are made of copper and the buckets fitted with gun metal spring rings instead of leather. Pumps made or lined with gun metal will last much longer than cast-iron, and if they are out of use for a time there is much less oxidation and consequent trouble in re-starting. For deep wells three-barrel pumps are generally to be preferred to single or double, the flow of water being more continuous and the work thrown on the motive power is more even. The pump is mounted on a strong platform in the well, and as near the water as possible. The author can recommend pump rods of wrought-iron made with T butt joints, with the bottom lengths working in the pumps of copper. Wooden connecting rods bound with iron are also used considerably, and sometimes light wrought-iron pipes. The connecting rods should be fitted with adjustable gun metal bearings. The pump rods should be arranged with guides and brackets at about every ten feet, as they work much stiffer and are less liable to bend or get out of truth. Roller guides can be recommended in lieu of ordinary fixed guides, which require constant lubrication and attention. An air vessel of ample capacity should be fitted to the rising main and the suction pipe have a foot valve and strainer. Very great care should be exercised in fixing the pump and rods in an exact vertical line. Should they be out of plumb the valves will probably be soon broken to pieces. When the pump is worked by toothed gearing, to secure noiseless and efficient running it is of great importance that the gearing is accurately pitched, and proportioned, and speeded; these are points that do not however always receive the attention they should do. When an engine and boiler are fixed at the top of the well and the engine geared direct, care should be taken with the foundations to ensure freedom from vibration, and the base-plate of the boiler can be extended with advantage. In the case of sinking, when geared pumps are driven by engine and belt, a driving centre of not less than 18 feet should be given. *Deep well* pumps are also now made in which two cylinders are placed one above another, and their buckets are worked by the same rod. The water is discharged alternately from the top and bottom cylinder into a main pipe. It is claimed for this arrangement that the flow of water is more uniform, and consequently the strain on the rods and working parts is reduced. Various forms of water valves are used for deep wells. Cornish double beat are suitable.

Geared Engine Frame for Deep Well Pumps.—These should be of substantial construction, to ensure steadiness in working. The end frames should be extended at the base, stayed together, and mounted on an extended bed plate. The crankshaft should be of wrought-iron or steel bent from the solid, cast-iron, which is sometimes used, is unreliable, and should never be employed for this purpose. The bearings should be of gun metal or phosphor-bronze, and be made adjustable for wear, and the connecting rods of wrought-iron fitted with adjustable bearings.

Pumps worked by Horse or Bullock Gear.—In raising water from deep wells by means of horse or bullock gear, treble barrel pumps can be recommended. Bullocks walk considerably slower than horses, and if employed the pump gearing must be speeded accordingly, and if a fly-wheel be fitted it will add much to the steadiness of working.

Ship's Pumps.—For washing decks, &c., on sailing ships, double force pumps arranged with double lever handles are largely employed. The handles are arranged with cross-bars to enable a number of men to work. For pumping salt water the working parts of pumps should be made of hard gun metal. Lengths of hose to reach to any part of the ship, with a full supply of fittings, should be provided and tested occasionally so as to be ready in case of fire. Treble crank vertical pumps with three buckets, placed one above another in a single barrel, and worked by handles or by chain from a steam winch, are also used; also the different forms of Woodbury Pumps. Double acting pumps driven by steam or hand power through the medium of chain wheels are also occasionally employed. By the use of a suction plate and "goose neck," water can be drawn from the sea or elsewhere. India-rubber disc pump valves with gridiron valve seats are suitable for this work.

Bilge Pumps.—On steamships or where steam is available, various forms of direct acting and other steam pumps are employed for pumping bilges, as fire pumps, &c. For pumping bilges where there is usually plenty of dirt, small pieces of wood, &c., it is important that a pump with valves of large area and of the simplest form be used to avoid choking. Ordinary lifting valves, which are more or less liable to jam in their seats, have been superseded in some cases by ordinary D type valves in both pump and steam cylinder, these are driven by an eccentric in the usual manner. Their action is perfectly certain, and as they cannot jam or choke they can be recommended for this and similar rough work, such as pumping thick fluids in gas and chemical works, &c. Mitre, clack, and ball valves of gun metal are still most generally employed, and in these cases strainers should always be used to prevent as far as possible dirt, &c., getting into the pump.

Surface Drainage Pumps, Scoop Wheels, &c.—As

a rule, in surface drainage a large quantity of water has to be lifted to a low height, and for this purpose scoop wheels, windmills, combined with pumps, chain pumps, centrifugal pumps, and heavy pumping engines are generally employed. The scoop wheel is made somewhat after the fashion of an undershot water wheel, but turned round in the opposite direction. In its action it scoops or pushes the water up a race in front of it, instead of being turned by the momentum of the water as in a water wheel. Scoop wheels can be driven by horse or steam power, and when once erected can be maintained at a low cost; where the lift is low, and it is necessary to keep water at a certain level, they can be used with advantage. If, however, a pump is only required to work occasionally, some other form, such as a centrifugal, will be cheaper and to be preferred (see also Chain Pumps). Horizontal and vertical spindle, centrifugal, and turbine pumps are used considerably, and are well suited, as from their simplicity of construction small obstacles, leaves, weeds, &c., can pass through the pump without damaging it. Where large tracts have to be drained turbine pumps are very serviceable, the types usually employed being single and double inlet, chiefly the former. Windmills driving force pumps require little attention, and are extremely useful auxiliary aids.

Pumps for Emptying Docks.—Centrifugal pumps, combined with engines driving directly on to the pump spindle, are largely used and are well suited for this purpose.

Pumps for Sugar Liquor, Thick Liquids, &c.—Treble barrel plunger or double acting piston pumps are suitable for this duty. The pump passages, valves, suction and delivery pipes should be large and free. Valves of the butterfly or clack type are suitable; the pump and working parts should be of gun metal.

Pumps for Tanneries.—Piston and plunger pumps are chiefly employed, and by means of hose the tan liquor can be drawn from a pit and be discharged at any desired point, either through pipes or wooden shoots. Pump, gun metal lined; valves, ball or clack. For very strong liquor the pumps are sometimes lined with lead alloy.

CHAPTER VII.

PUMP VALVES.

Pump Valves. – Perhaps the most important factor in the successful working of reciprocating pumps is the construction of the water valves. Should they be badly designed, or a type of valve ill-suited to the duty be employed, a very large percentage of useful effect may be lost. Pump valves may be divided into two chief classes—viz., hinged valves and vertical lift valves. The principal forms of valves in use are known as (1) Clack or flap valves; (2) Mitre, mushroom, conical, and puppet valves; (3) Disc valves; (4) Ball valves; (5) Double beat, multiple beat, or Cornish valves; (6) India-rubber conical and lip valves. There are, however, many modifications or combinations of these designed for special duties.

The Clack Valve, known also as the flap valve, is a simple form of valve more largely used than any other; it consists briefly of a disc hinged on one side, made usually either entirely of metal or of leather, or India-rubber *strengthened* and weighted by plates of iron, gun metal, or lead. The object of the plates is to give the valve sufficient weight to close quickly, when the pressure of the water rising below the valve ceases. When two of these valves are placed back to back, and hinged on a spindle in the centre of the passage, they are known as butterfly valves. For ordinary lifts and pumps running at a slow speed, clack valves can generally be recommended as being simple, inexpensive to repair, and trustworthy. They will also permit moderate sized obstacles to pass through them. The butterfly form of valve possesses an advantage over the ordinary clack valve of not interfering so much with the direct flow of the liquid being pumped, but it is rather more given to stick. It need hardly be said that whatever form of valve be used, it is a matter of great importance that the water has as free a passage through the pump as possible, and it has been given as a broad rule that to be effective the pump valves should be arranged with a water way at least equal to the area of the suction pipe. The valve to be desired is one which gives a maximum area of discharge for the water, with a minimum area subjected to the downward pressure and consequent concussion at the end of each stroke of the pump. This end the author is of opinion is largely attained by the employment of groups of ball valves, but this form of valve is only found suitable for moderate pressures. If clack valves are used for gritty water they should be made of gun metal. Clack valves are usually arranged to lift to an angle of about 45 deg., to permit of their closing themselves readily to avoid excess of "slip." Clack valves have the disadvantage of being rather sluggish in their action, and close with considerable concussion, hence the amount of water slip renders them generally unsuitable for high speeded steam pumps.

Mitre, Mushroom, Conical, and Puppet Valves.—These are made in a variety of forms of gun metal, India-rubber, &c., the metallic valves are turned and ground to fit accurately a conical opening in the seat. These valves hold water well when new, but unless they are made with a low lift, the constant shock from their sudden closing will soon cause them to wear and leak. From this cause chiefly they have for large pumps been to a great extent superseded by Cornish double beat or multiple valves. Mitre valves are usually bevelled to an angle of 45 deg. and fitted with feathers and stop to guide the beat of the valve. Valves of this type should be made as large as possible, to reduce the amount of lift required and consequent wear to the lowest point. Valve beats are made of iron, gun metal, lead, metallic compositions, and various woods, such as holly, box, lignum vitæ, &c., according to the duty required. If metals are used the valves and beats should be made of the same material to avoid galvanic action. If wood is employed for the valve seat holly can be recommended. Various more or less successful attempts in cushioning the closing of valves have been made, but we cannot here give them more than a passing notice; our readers will, however, find useful information on these and kindred points in a recently published book by P. R. Björling, entitled "Pump Construction." Valves of this type combine compactness with ready adjustment and quickness of closing, but are somewhat given to clog, except in the case of some India-rubber flexible conical valves which will permit the passage of foreign substances. Springs are sometimes employed to expedite the closing of these valves.

Ball Valves.--These are an extremely useful form of valve. They are very simple, and if carefully made and fitted will wear a long time, and with very little leakage. It is important to effective working that the balls have a greater specific gravity than the water, so that they will close readily without much pressure; if they have not, they may be given to "dancing," thus making a loss at every stroke of the pump. This is particularly the case when the suction is long and the delivery of water light. The balls are usually made of an India-rubber composition, a metallic ball covered with India-rubber, or of gun metal. If sufficiently heavy, the first is generally preferable to the second; owing to the difficulty of putting the metal exactly in the centre of the India-rubber they are apt to wear unevenly. A number of small valves is preferable to one or more large ones, as a much lower lift and consequent freedom from wear is secured; at the same time they are more readily repaired, and should one become out of order the pump is not disabled. The lift of these valves is regulated by a guard or cage. They can be recommended for use with heads of water not exceeding, say, 250 feet, and will be found much lighter in action than most other forms of valves. The balls should work in gun metal seatings, and if used for very hot water or long suction they themselves should be of gun metal.

Disc Valves.—These are usually made of discs of India-rubber or vulcanised fibre, mounted on a small vertical spindle resting on a grid and covered by a perforated plate, which acts as a guard, and regulates the lift of the valve. India-rubber being flexible and sensitive, and being easily renewed, makes an excellent valve for moderate lifts, as it readily rises and closes gently without shock, but they cannot be recommended for a greater lift than 25 feet. For large pumps a group of moderate sized valves can be recommended in preference to one large one. These are sometimes used with light springs fitted in the top of them to assist them in closing. The finest quality of rubber should be used, as it is less liable to crack at the spindle hole, which is sometimes the case with mixed rubber; but some mixed rubber has the advantage in weight, and the valve will therefore close more readily. Rubber, varying in thickness from half-an-inch to an inch, according to the size of the valve, is used, and a lift given to it in proportion to its diameter, say from one-eighth of an inch to three-eighths of an inch. All corners in the grid and guard should be carefully rounded to prevent the rubber cutting. Vulcanised fibre has of late been used considerably for valves in lieu of India-rubber, and it is claimed for this substance that the only effect that cold or hot water has on it is to increase its flexibility. It is said also to resist the action of oils, and is equally adapted to a direct lift as to a bending or cup guard.

Double Beat or Cornish Valves.—For large pumps double or multiple beat valves have mostly superseded other types, as they, in a great measure, get rid of the detrimental concussive action found in clack or conical valves, and the lift necessary is only about half that required by these valves. In the double beat valve what is practically two valves exist, as at each lift of the valve two spaces for the passage of the water are opened and the valve beats on two seats. The valve is cylindrical and beats on rings or seatings usually connected together by radiating feathers or plates. The valves for large pumps *are usually* made of iron, beating on seats of holly or other close grained wood, and if carefully designed and made will last a long time, and will work with very little leakage of water. It is very important however in designing valves of this type to secure their gentle closing, and that the amount of valve area subjected to the water pressure is carefully calculated and regulated according to the pressure.

India-rubber Conical and Lip Valves.—These are used to a moderate extent, and are made so that the water escapes either by the expansion or contraction of the India-rubber. In the case of lip valves the lips are forced open by the pressure of the water, and close themselves automatically through the natural elasticity of the India-rubber. A large variety of these valves have been designed, and for moderate duties some of them are very useful, but none can be recommended for high lifts. Whatever form of valve is employed, as we have elsewhere remarked, it is of the utmost importance that they are allowed to seat themselves easily and without jar, or they will rapidly hammer or cut themselves away, and require replacing. This is usually done by steam-cushioning or reducing the speed of the pump at the end of each stroke. The kind of pump and the duty it has to perform are the chief factors to be borne in mind in determining the best form of valve to employ, each of the great number of valves made may possess some feature in its construction to suit it particularly to some special duty, but no one form can be pronounced the best under all circumstances.

Leaky Pump Valves.—Leaky and worn valves and seats are a very fruitful cause for pumps failing to do their duty. Should the valve not be properly ground on its seat, in addition to the increase of "slip" or water leakage, the plunger will often suck air from the suction pipe, or through the packing, &c., and when the feed is turned on this is compressed and acts as a cushion between the plunger and the water, in some cases preventing the pump acting at all. The remedy for this is to have the valve re-ground, and should there not be one fitted, fix a pet cock for the release of the air.

CHAPTER VIII.

SUCTION AND DELIVERY PIPES, &c.

Depth of Suction.—Theoretically, a perfect pump will draw water from a depth of 34 feet, but in practice this can never be done. If the pump is in first rate condition, it will lift 25 feet or a little more, but as a pump can rarely be said to be in perfect order, a lift of say 15 feet, or even less if it can be conveniently arranged, will be found to give a much better effect, in fact, the shorter the lift the better the effect. This is particularly the case with high speed pumps, or when a pump is used for pumping thick or warm liquids. For hot liquids the suction should be done away with entirely. Centrifugal pumps will lift up to 20 feet, but about 7 or 8 feet will be found a much better working lift, and in these pumps also, the lower the lift the better the effect. It may be taken as a rule, that the faster the speed of the pump so in proportion should the length of the suction be reduced.

Suction Pipes, &c.—Suction pipes should be of ample size, as straight as possible, and perfectly air-tight; if bends are necessary, they should be of as large a radius as can be conveniently arranged. In all cases of long suctions or heavy lifts, foot or retaining valves should be fitted to the suction pipe, in fact, it is better to fit them in all cases, as they keep the pump ready charged with water. For heavy pressures a relief attachment is sometimes fitted, also suction pipes should always be of larger diameter than the delivery pipe. A rule sometimes employed for steam pumps is to make the suction pipe one-half the area of the pump chamber, with an increase in diameter for high speed pumps or those pumping thick fluids. If the suction is long the diameter of the pipe should be increased. Strainers should always be fitted, and the strainer holes be of ample area, say about three times that of the suction pipe; when on large pipes, the difficulty of cleansing them from obstructions, owing to their position at the foot of the suction pipe, has induced some makers to leave the foot of the suction pipe free, and attach the strainer to the suction opening of the pump itself.

Delivery Pipes.—All pipes should be truly cylindrical; wrought-iron pipes are to be preferred, at any rate for the smaller sizes, as they are lighter and less liable to fracture and can be bent to about 25 deg. without using elbows. They can be had in longer lengths than cast-iron, fewer joints are therefore required. Wrought-iron pipes, however, corrode quicker than cast. Cast-iron pipes vary more in thickness, and unless carefully cast from a proper mixture of iron are readily fractured by a blow, from unequal tension, frost, &c. Cold short iron should never be employed in the manufacture of pipes, but a mixture used that will give clean, smooth castings, free from blowholes; if these exist and the pipe is subject to heavy pressure or sudden change of temperature, it may fracture at any time and do serious damage. A skilled man will detect bad faults by the ring of the pipe when sounding with a hammer, but when pipes are to be used for heavy duties they should in all cases be tested by hydraulic pressure. This is often done by hand with the aid of a pair of differential plunger pumps. They are usually tested to about double their working pressure.

The diameter of delivery pipes should be uniform whether they be long or short. We have known of cases where the pipes have been gradually decreased in diameter; this practice is undoubtedly wrong, and the frictional flow of the water through the pipes is thereby considerably increased. Pipes should be laid to a regular and uniform slope, with as few elbows and angles as possible. There are, however, times when pipes have to be laid over suddenly rising ground, in these cases their diameter may be increased with advantage. For carrying pipes at an angle, ball and socket joints, universal joints, and goose necks are used.

When pumps are working under heavy pressure it is a good plan to fit an escape valve to the delivery side of the pump, as it relieves the pump from strain or fracture in case of an obstruction. This valve may be loaded or arranged to act at any desired pressure.

A check valve should always be fitted in the delivery pipe to relieve the pump from pressure when starting or when taken apart for adjustment or repairs. Pet cocks fitted on the suction and delivery pipes for testing the working of the pump are often very useful.

When two pumps discharge into the same main they should each be provided with an air chamber and check valve.

In starting pumps working against pressure it is convenient to have a waste delivery pipe fitted with a check valve, which can be closed when the check valve in the delivery pipe is opened and the pump properly started. Delivery pipes are usually made of a diameter equal to one-third to one-half the area of the working barrel, according to the length of the pipe or the speed of the pump. If the pipe is a very long one its diameter should be increased to allow for the increased water friction, but bends, angles, &c., increase the friction much more rapidly than length of pipe. Doubling the diameter of a pipe increases its capacity four times. Delivery pipes being liable to incrustation should always be ample size, this is particularly necessary when used for steam boiler feeding. Pressure pipes for hydraulic presses, &c., should be made especially strong, and carefully tested to at least 50 per cent. above the pressure at which they are intended to work. Oil can be recommended in preference to water for use with presses. If water is used it should be kept clean.

Pipe Joints, &c.—Flanged joints of different forms are usually employed for water pipes, but occasionally spigot and faucet joints are used. It will pay well to have all flange joints planed and the holes drilled to template, as unless the joints are well and carefully made, with heavy pressures, leakages are very liable to occur. For ordinary purposes we have found joints made with lead rings wrapped round with lamp cotton, or covered with cloth saturated with tar, stand very well. For heavy pressures, we can recommend a flanged joint with one end recessed, and the other one made with a corresponding projection; a cord of gutta-percha is inserted between the flanges and squeezed flat when the bolts are tightened up. This joint has stood successfully pressures of upwards of 700 lb. per square inch. For carrying compressed air, a flanged joint with an India-rubber washer inserted between them, or a spigot and faucet joint with the male and female ends turned and screwed, and with a thin lead washer, is suitable. In this latter case, the screw threads should be lightly covered with white lead, but we do not recommend the making of complete joints with red or white lead.

Speed of Water through Pipes.—Although water can be made to flow through suction pipes up to a speed of 500 feet per minute, the actual working speed attempted—except, perhaps, in steam fire pumps—should not exceed 250 feet per minute, and a speed of, say, 200 feet per minute is to be preferred. As the fluid friction in the pipes increases in the proportion of the square of the velocity, it follows that if pumps are driven at a very high speed a considerable loss of power through friction occurs.

Hose Couplings, &c.—Hose couplings are now made with both ends alike—not male and female—and can be joined or unjoined by a quarter turn of the wrist, and the pressure of the water helps to keep the joint tight. This is preferable to the ordinary joints, it is not liable to get burred, and in case of fire much time is saved. If hose is used for suction it should be strongly wired and lined. Canvas rubber-lined hose has, of late, largely taken the place of leather hose, it is considerably lighter than leather, less liable to leakage, and does not require the same amount of trouble to keep it in condition. It is manufactured to resist a water pressure of some 300 lb. to the square inch, but this pressure is rarely, if ever, required.

RULES RELATING TO PIPES, &c.

To find the pressure per square inch of a column of water (Telford).—Multiply the height in feet by ·434. The pressure per circular inch may be found by multiplying the height in feet by ·341.

Example.—Required the pressure in pounds per square inch of a column of water 200 feet high:

200 × ·434 = 86·8 lbs. per square inch.

A ready way of ascertaining approximately the pressure is to take half the height in feet, the difference being on the side of safety.

To find the pressure of a column of water in pounds.—If the base be circular, square the diameter in inches, and multiply by ·341 or ·34, which gives the weight of 1 foot in height; therefore, by multiplying by the number of feet in height, the pressure is found. If the base be square, multiply by ·434.

Examples.—Required the pressure of a column of water 12 inches in diameter and 20 feet high:

12 × 12 × ·341 × 20 = 982·080 lbs. if the base be circular.

12 × 12 × ·434 × 20 = 1249·920 lbs. if the base be square.

To find the quantity of water in a pipe.—The square of the diameter in inches gives the weight of water in pounds for 3 feet in length, and by striking off one figure to the right the number of gallons is found.

Example.—Required the quantity of water which a pipe 15 inches in diameter and 9 feet long will contain:

$$15 \times 15 \times 3 = 675 \text{ lbs., or } 67{\cdot}5 \text{ gallons.}$$

To find the diameter of Pipe required to discharge a given quantity of water at a given speed per minute.

Rule.—Multiply the number of cubic feet of water per minute by 144, divide by the velocity of flow in feet per minute, divide by ·7854, and take out square root, which will give diameter of pipe.

To find the velocity of flow of water in a pipe required to discharge a given volume of water in a given time.

Rule.—Multiply the number of cubic feet of water by 144, and divide the product by the area of the pipe in inches.

To calculate the area of Pipes by the Slide Rule.—Set 7·854 on the C line to 1 or 10 on D line. D is a line of diameters and C a line of areas, for against the diameter on D is the area on C.

To find loss of head due to the friction of water in straight pipes (Prony's rule).—Multiply 2·25 times the length of the pipe in miles by the square of the velocity of the water in the pipe in feet per second, and divide the product by the diameter of the pipe in feet; the result will be the head of water in feet required to balance the friction. Bends in pipes diminish the velocity of the water

·0039 times the sum of the sines of the several angles of inflection.

To find weight of Cast-iron Pipes.—From the square of the outside diameter subtract the square of the inside diameter in inches, multiply the result by 7 and divide the product by 3, which will give the weight in pounds (approx.) of one foot of pipe.

PRESSURE OF WATER

AT DIFFERENT HEADS IN POUNDS PER SQUARE INCH.

Head of water in feet.	Head of water in yards.	Head of water in fathoms.	Head of water in metres.	Pressure in lbs. per square in.	Head of water in feet.	Head of water in yards.	Head of water in fathoms.	Head of water in metres.	Pressure in lbs. per square in.
10	3·33	1·66	3·04	4·33	150	50·0	25·0	45·7	64·9
20	6·66	3·33	6·09	8·66	160	53·3	26·6	48·7	69·3
30	10·0	5·0	9·14	12·9	170	56·6	28·3	51·8	73·6
40	13·3	6·66	12·1	17·3	180	60·0	30·0	54·8	77·9
50	16·6	8·33	15·2	21·6	190	63·3	31·6	57·9	82·3
60	20·0	10·0	18·2	25·9	200	66·6	33·3	60·9	86·6
70	23·3	11·6	21·3	30·3	210	70·0	35·0	64·0	90·9
80	26·6	13·3	24·3	34·6	220	73·3	36·6	67·0	95·3
90	30·0	15·0	27·4	38·9	230	76·6	38·3	70·1	99·6
100	33·3	16·6	30·4	43·3	240	80·0	40·0	73·1	103·9
110	36·6	18·3	33·5	47·6	250	83·3	41·6	76·2	108·3
120	40·0	20·0	36·5	51·9	260	86·6	43·3	79·2	112·6
130	43·3	21·6	39·6	56·3	270	90·0	45·0	82·2	116·9
140	46·6	23·3	42·6	60·6	280	93·3	46·6	85·3	121·3

A pipe one yard long holds as many pounds of water as the square of its diameter in inches: thus a 4-inch pipe *holds 16 lb.* of water for each yard of length.

WEIGHT OF WATER

IN PIPES OF VARIOUS DIAMETERS, I FOOT IN LENGTH.

Diameter in inches.	Weight in pounds.	Diameter in inches.	Weight in pounds.	Diameter in inches.	Weight in pounds.
3	3	13	57½	26	230½
3¼	3½	13¼	59¾	26½	239½
3½	4¼	13½	62¼	27	248½
3¾	4¾	13¾	64½	27½	257¾
4	5½	14	66¾	28	267¼
4¼	6¼	14¼	69¼	28½	276¾
4½	7	14½	71½	29	286½
4¾	7¾	14¾	74¼	29½	296½
5	8½	15	76¾	30	306¾
5¼	9¼	15¼	79¼	30½	317¼
5½	10¼	15½	82	31	327½
5¾	11¼	15¾	84½	31½	338¼
6	12¼	16	87¼	32	349
6¼	13¼	16¼	90	32½	360
6½	14¼	16½	92¼	33	371¼
6¾	15½	16¾	95½	33½	382½
7	16¾	17	98½	34	394
7¼	18	17¼	101½	34½	405¾
7½	19¼	17½	104½	35	417½
7¾	20½	17¾	107½	35½	429½
8	21¾	18	110½	36	441¾
8¼	23¼	18¼	113⅓	36½	454
8½	24½	18½	116½	37	466½
8¾	26	18¾	119¾	37½	479¼
9	27½	19	123	38	492¼
9¼	29¼	19¼	126¼	38½	505¼
9½	30¾	19½	129½	39	518½
9¾	32½	19¾	132	39½	531¾
10	34	20	136¼	40	545½
10¼	35½	20½	143¼		
10½	37½	21	150¼		
10¾	39¼	21½	157½		
11	41¼	22	165		
11¼	43¼	22½	172½		
11½	45	23	180¼		
11¾	47	23½	188¼		
12	49	24	196¼		
12¼	51	24½	204½		
12½	53¼	25	213		
12¾	55½	25½	221½		

HEIGHTS DUE TO VELOCITIES PRODUCED BY GRAVITY.

Velocity in feet per second.	Height.	Velocity in feet per second.	Height.	Velocity in feet per second.	Height.
1	0·01553	31	14·922	68	71·800
2	0·06211	32	15·900	70	76·087
3	0·13975	32·2	16·100	72	80·497
4	0·24844	33	16·910	74	85·029
5	0·38819	34	17·950	76	89·688
6	0·55900	35	19·021	78	94·471
7	0·76086	36	19·813	80	99·379
8	0·99377	37	21·257	82	104·41
9	1·2577	38	22·422	84	109·56
10	1·5528	39	23·618	86	114·84
11	1·8789	40	24·844	88	120·25
12	2·2360	41	26·102	90	125·77
13	2·6241	42	27·391	92	131·43
14	3·0434	43	28·711	94	137·20
15	3·4937	44	30·062	96	143·10
16	3·9751	45	31·444	98	149·07
17	4·4875	46	32·857	100	155·28
18	5·0310	47	34·301	102	161·55
19	5·6055	48	35·776	104	167·95
20	6·2111	49	37·282	106	174·47
21	6·8477	50	38·820	108	181·11
22	7·5153	52	41·987	110	187·88
23	8·2141	54	45·279	112	194·78
24	8·9441	56	48·695	114	201·8
25	9·7048	58	52·235	116	208·9
26	10·497	60	55·870	118	216·21
27	11·320	62	59·689	120	223·6
28	12·174	64	63·602	122	231·1
29	13·059	64·4	64·400	124	238·7
30	13·975	66	67·639	126	246·5

The height is found by squaring the velocity and dividing by 64 and the velocity is found by reversing the process.

Cement for Faced Steam Joints.—Powdered plu bago, one part; red lead, one part; white lead, one pa mix with boiled linseed oil.

Cement for Steam and Water Joints.—Grou litharge, 5 lb.; plaster of Paris, 2 lb.; yellow och ¼-lb.; red lead, 1 lb.; hemp cut into ½-in. lengths, ¼-o mix with boiled linseed oil.

Cement for Iron Tubes, &c.—Finely powdered iron, sixty parts; sal ammoniac, one pint; sufficient water to form a paste.

Cement for Plumbers.—Black resin, one part; brick-dust, two parts; melt together.

Cement for Pipe Joints.—Fine iron filings, ten parts; chloride of lime, three parts; sufficient water to make a paste. After the pipes are joined leave them a few hours before using.

Rust Joint Cement for Cast-iron Cisterns.—Cast-iron borings, 5 lb.; powdered sal ammoniac, 1 oz.; flour of sulphur, 2 oz.; mix with water. Another and perhaps better cement is composed of cast-iron borings, 6 lb.; powdered sal ammoniac, 1 oz.; flour of sulphur, ½-oz.; mix with water.

Coating for Iron Pipes.—One of the methods practised by Dr. Angus Smith for protecting iron pipes is as follows:—The ingredients consist of coal tar and pitch oil in the proportion of one part tar to three of oil. The mixture is heated to the boiling temperature of the oil, and the castings are immersed in it and allowed to remain until the same temperature is diffused throughout the mass. The pipes are then gently withdrawn, the naphtha and other volatile oils evaporating and drawing off the iron, so that whilst still very hot a firm hard coating of pitch is left, which firmly adheres to the iron. Care should e taken to heat the mixture to the proper degree—viz., 50 to 450 deg. Fahr. If it is made too hot, the pitch will e overheated, and afterwards scale off.

CHAPTER IX.

RULES AND NOTES RELATING TO PUMPS, &c.

It must be borne in mind that, in practice, all pumps lift much less water than they should do theoretically, calculated by their dimensions and speed, and the amount depends largely on the design and condition of the pump, valves, &c. The amount usually deducted for losses by leakage, &c., is from one-third to one-half, according to the condition of pump.

To find the area of a Pump Barrel or Cylinder.—Square its diameter and multiply by ·7854.

The area of a Steam Piston, multiplied by the pressure of steam gives the amount of power exerted.

The area of the Water Piston, multiplied by the pressure of water per square inch, gives the resistance.

***To find* the capacity of a Pump Cylinder.**—Multiply *its area in* square inches by the length of stroke in inches.

To find the load on a Pump.—Multiply the area of the pump in inches by the weight of the column of water in pounds per square inch.

To find the quantity of water in cubic inches delivered per hour.—Multiply the net quantity of water delivered per stroke by the number of strokes per minute and by 60.

To find the quantity of water in cubic feet delivered per hour.—Divide the quantity delivered in cubic inches per hour by 1728.

To find the time required to pump a given quantity of water.—Divide the quantity of water in cubic feet to be pumped by the number of cubic feet of water per hour the pump will discharge.

To find the velocity of water in a Pump.—Multiply the length of stroke in feet by the number of strokes per minute, the answer will give number of feet per minute.

To find the quantity a Tank will contain.—Multiply the length, width, and depth together, and multiply the product by 6·25, the result will be the number of gallons the tank will hold.

To find the quantity of water elevated in one minute, running at 100 feet piston speed per minute.—Square the diameter of water cylinder in inches and multiply by four, the result will give gallons per minute, approximately.

To find height of Lift required for Vertical Lifting water valves.—Divide the area of the valve opening in inches by its circumference in inches; this will give the height of lift required for the valve, which should equal one-fourth the diameter of the valve.

To find the Horse-power necessary to elevate water to a given height.—Multiply the total weight of the column of water in pounds by the velocity per minute in feet, and divide the product by 33,000 (allowing at least one-third for loss by slip, friction, &c.).

To find the quantity (approximately) of water in gallons delivered by a pump per minute.—Square the diameter of the pump in inches and multiply by ·034 and the product by the speed of the pump in feet.

To find the Horse-power required to raise a given quantity of water in gallons to a given height in feet.—Multiply the given number of gallons of water to be raised per minute by 10, and by the height the water has to be raised in feet, and divide the product by 33,000.

To calculate the duty of Pumping Engines.—(Bailey). *Rule.*—Multiply the area of the plunger in square inches by the pressure per square inch in pounds, this to give the load in pounds; multiply by the feet per hour travelled by the plunger, and by the constant 100, and divide by the coal per hour in pounds, the result gives the number of pounds of water lifted one foot high by 100 lb. of coal.

***Formula* to find Horse-power of Pumping Engines**

(Appleby). — G=the number of gallons required per hour; C=the number of cubic feet required per hour; F=the height in feet to which the water is to be raised; =Horse-power—

$$\text{Then} = \frac{G \times F}{198{,}000} \quad \text{or} = \frac{C \times F}{31{,}750}$$

About 70 or 80 per cent. must be added to the number obtained by the above formula to allow for frictional and other contingencies; the result obtained by the formula is not in nominal but in actual horse-power (33,000 ft. lb.).

What size of Pump and what Horse-power is required to raise a certain amount of water in a certain time (Meatyard)?—A gallon of water weighs 10 lb., hence if it be desired to raise 1,000 gallons per hour to a height of 100 feet, the load to be raised would be 10,000 lb. 100 feet high. This 10,000 lb. raised 100 feet high is equal to raising 1,000,000 lb. 1 foot high. Dividing the 1,000,000 lb. by 60 we have 16,666⅔ lb. to be raised in 1 minute.

A horse-power is represented by 33,000 lb. raised 1 foot high per minute, hence the horse-power required to raise the 16,666⅔ lb. 1 foot in 1 minute would be ascertained by dividing 16,666⅔ by 33,000. This gives ·505 horse-power, or a little over one-half horse-power. To overcome any contingencies, friction, &c., these small powers are generally doubled; for larger powers a percentage of 60 to 70 is added. In the case mentioned the power required to assure the delivery of 1,000 gallons at a height of 100 feet in 1 hour would be 1 horse-ower.

To develop a formula we may represent the number of allons to be raised in 1 minute by *G* and the height by *h*, when the horse-power required would be represented by $\frac{G \times 10 \times h}{33{,}000}$. If the amount required be expressed in cubic feet instead of gallons the formula would be $\frac{6\frac{1}{4}\ G \times 10 \times h}{33{,}000}$, there being 6¼ gallons to the cubic foot, and 10 lb. to the gallon of water or 62·5 lb. to the cubic foot.

To find the size of pumps required, let *D* represent the diameter of pumps in inches; *S*, the number of strokes per minute; *L*, the length of stroke of pump in feet; *F*, the cubic feet delivered per minute; *G*, the number of gallons delivered per minute. Then $F =$

$$\frac{D^2 \times {\cdot}7854}{144} \times L \times N \times {\cdot}00545\ D^2\ L\ N \ \ldots\ldots\ldots\ldots (1)$$

$$D^2 = \frac{F}{{\cdot}00545\ L\ N}$$

$$D = \sqrt{\frac{F}{{\cdot}00545\ L\ N}} \ \ldots\ldots\ldots\ldots (2)$$

$$G = 6{\cdot}25\ F = 6{\cdot}25 \times {\cdot}00545\ D^2\ L\ N.$$

$$G = {\cdot}034\ D^2\ L\ N \ \ldots\ldots\ldots\ldots (3)$$

$$D = \sqrt{\frac{G}{{\cdot}034\ L\ N}} \ \ldots\ldots\ldots\ldots (4)$$

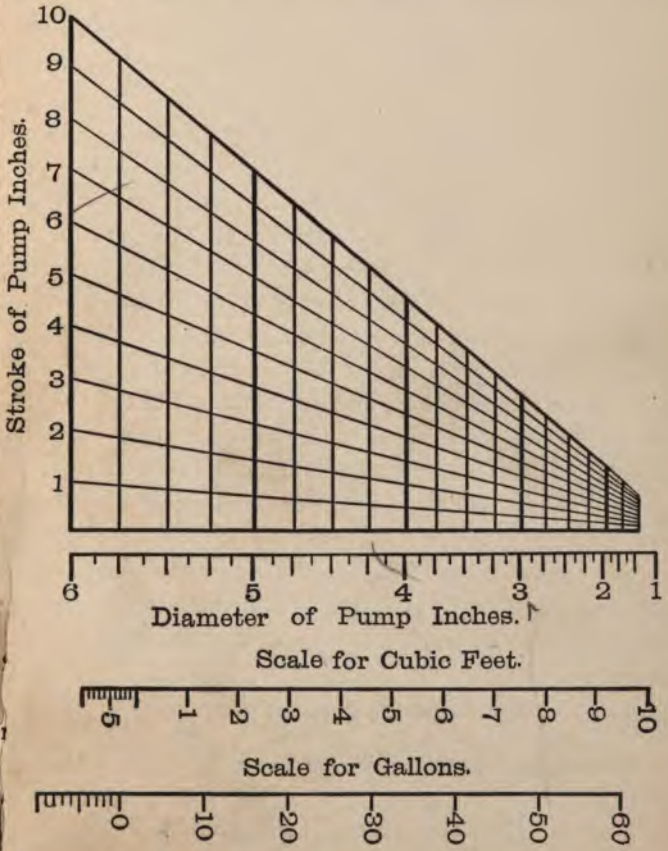
1½ = 4¼ approximate difference in level of fore foot and heel; raised 4½ inches in 1·57 minutes is equal to one foot high in 4·19 minutes; the total tonnage is 18,750 tons, so $\frac{18{,}750}{4{\cdot}19} = 4{,}475$ tons—*i.e.*, 18,750 tons in 4·19 minutes = 4,475 in 1 minute.

$$\frac{4{,}475 \times 1}{16{\cdot}5} = 271 \text{ horse-power.}$$

$$384{\cdot}6 + 377{\cdot}3 + 271 = 1{,}032{\cdot}9 \text{ horse-power.}$$

Capacity of a Pump.—The capacity of a pump ranges from 70 to 85, the displacement of the piston varying with the speed at which the pump runs.

Discharge from Reciprocating Pumps.—We give here a diagram for finding the *theoretical* discharge from reciprocating pumps published by the *Practical Engineer*, which says:—



The accompanying diagram of discharge from reciprocating pumps, giving the *theoretical* quantity the pump will discharge per hour for every one effective stroke per minute, either in gallons or cubic feet, is one which will be found useful in many cases, where calculations concerning the required size of pumps or the time occupied in filling ballast or other tanks, &c., have to be made; for with the aid of this diagram it is only necessary to ascertain the number of effective strokes the pump makes per minute to obtain the quantity of water it should pump per hour.

For example, suppose we have a double-acting pump, 5 in. diameter by 8 in. stroke, making 160 strokes per minute, required the quantity of water it will pump per hour.

With a pair of dividers measure from the base of the diagram at the point marked 5 in. on the scale of diameters the height of the ordinate up to the line marked 8 in. on the scale for stroke of pump to the left of the diagram; transfer this distance to the scales of gallons and cubic feet, and read off 34 and 5·4 as the quantity of water the pump will deliver per hour for every one effective stroke per minute in gallons and cubic feet respectively.

Then gallons per hour $= 34 \times 160 = 5{,}440$.
For $5^2 \times {\cdot}7854 \times 8 = 157{\cdot}08$ cubic inches per stroke,
and $157{\cdot}08 \times 160 = 25132{\cdot}8$ cubic inches per minute;
and $25132{\cdot}8 \times 60 = 1{,}507{,}968$ cubic inches per hour, which, divided by 277·25, the number of cubic inches in the gallon,

$$\frac{1{,}507{,}968}{277{\cdot}25} = 5{,}440 \text{ gallons per hour;}$$

or, dividing by 1,728, the number of cubic inches in a cubic foot,

$$\frac{1{,}507{,}968}{1{,}728} = 5{\cdot}4 \text{ cubic feet per hour.}$$

This diagram may also be used inversely, as in the following case: A pump is required to deliver 5,440 gallons per hour, to be worked by an engine which makes 160 strokes per minute. In this case the length of stroke must first be decided, and should be made such that the mean speed of the plunger does not exceed 120 feet per minute; or taking it at 110, then

$$\text{Length of stroke} = \frac{110}{160} = \cdot 68 \text{ ft.} = \text{say } 8 \text{ in.}$$

Next divide the gallons per hour by the strokes per minute, which, assuming the pump to be a double-acting one, in this case $= \frac{5,440}{160} = 34$ gallons per hour for every one stroke per minute; then take this value on the scale for gallons (see diagram), and run along the line corresponding with 8 in. stroke until the other leg of the compass touches the base line, and read off the required diameter 5 in. It may here be remarked that this gives the theoretical diameter for the pump; in practice it is usual to increase it by about 20 per cent., which can, however, be allowed for when using this diagram by adding 20 per cent. to the gallons per hour at the start.

This diagram will also be found useful to find the time in which a pump will empty a tank. For the solution of this question we have the formula—

$$\text{Time in hours} = \frac{\text{Cubic feet of water in tank.}}{\text{Cubic feet pumped out in an hour.}}$$

Suppose, then, we have a tank, say of 2,628 cubic feet capacity, filled with water, and we require to know how many hours it will take a pump, say 5½ in. diameter by 9 in. stroke, making 120 effective stroke per minute, to empty it.

At the point on the scale of diameters, at the base of the diagram marked $5\frac{1}{2}$ in., take with a pair of dividers the height of the ordinate up to the line corresponding with 9 in. stroke, which by the scale for cubic feet equals 7·3, which multiplied by 120 equals 876 cubic feet per hour; therefore,

$$\text{Time in hours} = \frac{2{,}628}{876} = 3.$$

Also this diagram will be found useful in cases where one larger pump, making a given number of strokes per minute, is to be substituted for two or more smaller pumps making different strokes per minute, to pump the same quantity of water per hour, and many other cases.

NOTES.—If the quantity of water is given in lbs. ÷ 10 = gallons, or 62·5 = cubic feet; if in tons × 224 = gallons or 35·84 = cubic feet fresh water, or 35 = sea water—

$$\text{Gallons} \times \cdot 16 = \text{cubic feet.}$$

A rule which the author has found very useful in practice for the quantity of water that a pump will deliver in gallons per hour is

GPh

$$G = D^2 S N \times \cdot 1698$$

In which G = the gallons per hour.

D = the diameter of the pump in inches.

S = the stroke of the pump in inches.

N = number of effective strokes per minute.

or approximately $G = D^2 S N \times \cdot 17$

whence $D = \sqrt{\dfrac{G}{S N \times \cdot 17}}$

and $N = \dfrac{G}{D^2 S \times \cdot 17}$

$S = \dfrac{G}{D^2 N \times \cdot 17}$

In practice, the constant ·17 varies from ·10, giving 60 *per cent.* efficiency, to ·16, giving 95 per cent. efficiency.

NOTES RELATING TO PUMPS.

Freezing point or 32 deg. Fahr. = Zero in Cent. or Reaumur.

Boiling point or 212 deg. Fahr. = 100 deg. Cent. or 80 deg. Reaumur.

One cubic foot water = 6¼ gallons.

Two feet vertical head water = 1 lb. pressure.

One atmosphere = 15 lbs. per square inch, nearly.

An imperial gallon of water at 62 deg. Fahr. weighs 10 lb. avoirdupois.

Gallons multiplied by ·16045 = cubic feet.

Cubic feet multiplied by 6·232 = number of gallons.

Gallons multiplied by 277·274 = cubic inches.

Cubic inches multiplied by ·00360 = number of gallons.

Cubic feet of water × 62·35 = number of lb. weight.

Pound of water multiplied by ·0160 = cubic feet.

Gallons of water × ·0044 = number of tons.

Tons of water × 223·897 = gallons of water.

Cubic feet of water × 35·92 = number of tons.

Tons of water × ·02783 = cubic feet of water.

A cubic foot of water weighs 62·5 pounds.

A cubic foot of water contains 6·25 gallons.

A ton of water is 224 gallons.

A ton of water = 35·9 cubic feet.

A column of water produces a pressure in lbs. per square inch equivalent (approx.) to half the height in feet.

One gallon = 4·543 litres.

One kilogramme = 2·2 lbs.

One metre = 3·28 feet.

One square metre = 10·76 square feet.

Water is at its greatest density when at a temperature of 39·1 deg. Fahr. Water expands as its temperature is increased above 39·1 deg. The rate of expansion above

212 deg. Fahr. is unknown. Each degree of difference in temperature of feed water to a boiler makes a difference of ·00104 in the amount of evaporation.

A column of water 1 foot high = pressure of ·434 lbs. per square inch.

A column of water 1 foot high = (approx.) pressure of ½-lb. per square inch.

A pressure of 1 lb. per square inch = column of water 2·31 feet high.

One litre of water = ·22 gallons.
One litre of water = 61 cubic inches.
One litre of water = ·0353 cubic feet.
One cubic metre of water = 220 gallons.
One cubic metre of water = 1·308 cubic yards.
One cubic metre of water = 35·31 cubic feet.
One cubic metre of water = 1,000 kilos.
One cubic metre of water = 1,000 litres.
One cubic metre of water = 1 ton (approx.).
One kilo of water = 2·204 lbs.

HYDRAULIC NOTES.

WATER PRESSURE.

H = Head of water in feet.

P = lb. pressure per square inch. H = P × 2·31. P = H × ·4333.

Pressure in the Mains.—The average working pressure is 700 lbs. per square inch with accumulators, but it varies from 300 to 1,500 lbs. per square inch.

700 lbs. per square inch = 549·78 lbs. per circular inch, equivalent to a head of 1,613·2 feet.

Effective Pressure with 700 lbs. at Accumulator.

Ratio of multiplying power	2 to 1	4	6	8	10	12	14	16
Multiply by	·8	·76	·72	·67	·63	·59	·54	·5
Effective pressure in lbs.	560	532	504	469	441	413	378	350

Horse-power required to pump one gallon of water against various pressures, allowing 40 per cent. for friction.

Pressure per square inch.	Calculated with 40 per cent. added.	Horse-power required.
700	0·68	say ·75
1,500	1·47	„ 1·75
2,240	2·19	„ 2·5

Speed of water should not exceed 100 feet per minute with 700 lbs. pressure.

Mechanical Value of Fluids under Pressure.—W = 144 PCK. W = units of useful work in foot lb. P = pressure in lbs. per square inch. C = quantity used in cubic feet. K = co-efficient of effect found by experiment, and varying with the class of machine or arrangement.

Table of power required to raise water from deep wells (Appleby).

Gallons of water raised per hour	200,	350,	500,	650,	800,	1,000
Height of lift for one man working on crank in feet	90,	52,	36,	28,	22,	18
Height of lift for one donkey working on gin in feet ...	180,	102,	72.	56,	45,	36
Height of lift for one horse working on gin in feet ...	630,	357,	252,	196,	154,	126
Height of lift for one horse-power steam engine in feet	990,	561,	396,	308,	242,	198

This table is based on the assumption that a good class of treble or double barrel lift pump is used, with valves in the buckets, with an additional retaining valve for lifts above 100 feet.

TABLE OF AREAS OF CIRCLES.

Diam.	Area.	Diam.	Area.	Diam.	Area.	Diam.	Area.
⅛	·0122	6 in.	28·274	23½ in.	433·731	47 in.	1734·94
¼	·0490	¼	30·679	24 in.	452·390	½	1772·05
⅜	·1104	½	33·183	½	471·436	48 in.	1808·56
½	·1963	¾	35·784	25 in.	490·875	½	1847·45
⅝	·3068	7 in.	38·484	½	510·706	49 in.	1885·74
¾	·4417	¼	41·282	26 in.	530·930	½	1924·42
⅞	·6013	½	44·178	½	551·547	50 in.	1963·49
1 in.	·7854	¾	47·173	27 in.	572·556	½	2002·96
⅛	·9940	8 in.	50·265	½	593·958	51 in.	2042·82
¼	1·2271	¼	53·456	28 in.	615·753	½	2083·07
⅜	1·4848	½	56·745	½	637·941	52 in.	2123·71
½	1·7671	¾	60·132	29 in.	660·521	½	2164·75
⅝	2·0739	9 in.	63·617	½	683·494	53 in.	2206·18
¾	2·4052	¼	67.200	30 in.	706·860	½	2248·00
⅞	2·7611	½	70.882	½	730·618	54 in.	2290·22
2 in.	3·1416	¾	74·662	31 in.	754·769	½	2332·82
⅛	3·5465	10 in.	78·540	½	779·313	55 in.	2375·82
¼	3·9760	¼	82·516	32 in.	804·249	½	2419·22
⅜	4·4302	½	86·590	½	829·578	56 in.	2463·00
½	4·9087	¾	90·762	33 in.	855·30	½	2507·18
⅝	5·4119	11 in.	95·033	½	881·41	57 in.	2551·75
¾	5·9395	¼	99·402	34 in.	907·92	½	2596·72
⅞	6·4918	½	103·869	½	934·82	58 in.	2642·07
3 in.	7·0686	¾	108·434	35 in.	962·11	½	2687·82
⅛	7·6699	12 in.	113·097	½	989·80	59 in.	2733·97
¼	8·2957	½	122·718	36 in.	1017·87	½	2780·50
⅜	8·9462	13 in.	132·732	½	1046·35	60 in.	2827·43
½	9·6211	½	143·139	37 in.	1075·21	½	2874·75
⅝	10·320	14 in.	153·938	½	1104·46	61 in.	2922·46
¾	11·044	½	165·130	38 in.	1134·11	½	2970·57
7/4	11·763	15 in.	176·715	½	1164·15	62 in.	3019·07
4 in.	12·566	½	188·692	39 in.	1194·59	½	3067·96
⅛	13·364	16 in.	201·062	½	1225·42	63 in.	3117·24
¼	14·186	½	213·825	40 in.	1256·64	½	3166·92
⅜	15·033	17 in.	226·980	½	1288·25	64 in.	3216·99
½	15·904	½	240·528	41 in.	1320·25	½	3267·45
⅝	16·800	18 in.	254·469	½	1352·65	65 in.	3318·30
¾	17·720	½	268·803	42 in.	1385·44	½	3369·55
⅞	18·665	19 in.	283·529	½	1418·62	66 in.	3421·19
5 in.	19·635	½	298·648	43 in.	1452·20	½	3473·22
⅛	20·629	20 in.	314·160	½	1486·17	67 in.	3525·65
¼	21·647	½	330·064	44 in.	1520·53	½	3578·47
⅜	22·690	21 in.	346·361	½	1555·28	68 in.	3631·68
½	23·758	½	363·051	45 in.	1590·43	½	3685·28
⅝	24·850	22 in.	380·133	½	1625·97	69 in.	3739·28
¾	25·967	½	397·608	46 in.	1661·90	½	3763·66
⅞	27·108	23 in.	415·576	½	1698·23	70 in.	3848·45

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